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THE SYSTEM DYNAMICS OF PRODUCT DEVELOPMENT CONTROL

A THESIS

Presented To

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by

Thomas Bowles Clark

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SUMMARY

The research was done at the request of the Whirlpool Corporation. The objective of the study was to explore the dynamics of the complex system in which Whirlpool would operate if Whirlpool undertakes the development and marketing of a revolutionary household trash disposal appliance. The motivation for the research is the belief that a manager who understands the dynamics of a system is in an improved position to exercise control over the system.

The philosophy and techniques of industrial dynamics were applied in the study. A conceptual qualitative mode of cause-and-effect relationships was constructed. The model shows the interacting environmental factors which lead to the development of a market for the disposal appliance, Whirlpool's eventual perception of that market, and the subsequent allocation of development effort and sales effort to the product. The DYNAMO computer simulation language was used to quantify the model. Simulation experiments on the model led to an understanding of the feedback characteristics of the system that control system behavior.

The importance of the government's reactions to the waste disposal problem and its possible alternative solutions became apparent. It was found that Whirlpool could exercise a significant degree of control over the entire system by influencing the government's reactions to the problem. It was demonstrated that by developing the capability of the disposal device, Whirlpool can indirectly cause pressures to be set up

within the system which will stimulate the development of a market for the product, whereas waiting for a market to form can allow pressures to build which will stifle the growth of the market.

CHAPTER I

INTRODUCTION

The average American consumes twice as much in the way of goods as he consumed during the years just prior to World War II (10). This fact coupled with the rapidly rising population has caused a sharp increase in the amount of waste produced in the nation. Each day the people of the United States produce 800 million pounds of solid wastes, and this figure is expected to reach 2.4 billion pounds by 1980 (4). These figures include domestic and commercial trash, industrial waste, leaves and other outdoor trash, scrapped equipment and building materials. The collection and disposal of this waste is costing the public more than 1.5 billion dollars per year, a figure exceeded only by the annual outlays for schools and highways (4).

The technology needed to cope with the problem has not kept pace with the magnitude of the problem itself. It is the common opinion of many experts in the field that the nation is well over ten years behind in coming to grips with the problem of solid waste disposal (1). Wesley E. Gilbertson, Chief of the Office of Solid Wastes for the Public Health Service, described the situation in an address to the Public Works Congress and Equipment Show held in Chicago in September of 1966:

> Man, with his infinite technological ability, has succeeded in burdening himself with a solid waste problem as remote from the past as the supersonic jet is from the oxcart. And despite his technological prowess, man has not yet adequately turned his talents toward solving the problems of waste management.

We are, as someone has said, a generation standing knee-deep in its own refuse, hurling spaceships to the moon.

Realizing the great magnitude of the disposal problem and the lack of relief in the foreseeable future, the Whirlpool Corporation is considering the development and marketing of a household trash disposal appliance. This appliance, it is hoped, would be capable of handling any type of household trash and would therefore be a significant improvement over the presently available under-the-sink garbage disposers. Since the development of this product has not yet begun, it is not known at this point how the appliance is to operate.

The management of the development and marketing of a new product is a task with which the managers of Whirlpool have had a great deal of experience. This product, however, imposes several peculiarities which will complicate the management and control process.

The first complicating factor is the nature of the market. Most products are purchased for one of two reasons or a combination of both. The product may solve some personal problem or fill some particular need, an example being gasoline for an automobile. Other products serve mainly as luxury items or status symbols, such as jewelry. Most products fit into both categories. The new automobile, color television set, or washing machine fill some personal need and are sources of pride for the owner.

A sophisticated trash disposal appliance, however, would not fit into either of the above categories at this time. It is meant to serve a purpose and help solve a problem, but the problem does not yet exist on a personal level. Most Americans do not know or care about what happens to their garbage once it has been picked up, and in fact, very few people realize how large a proportion of their tax dollar is spent on waste disposal (4). It will most probably be no easier to place the trash into the trash disposal appliance than it is to place it into a trash can. Furthermore, the disposer may require the handling of chemicals, the replacing of filters, or other bothersome and expensive maintenance and repair. It hardly seems reasonable to expect a man to purchase and install such an appliance if the trash truck still passes his house every day and collects his neighbors' trash (14, p. 11). Therefore, although the product may help to treat a national and municipal problem, the individual consumer, for the most part, has not yet realized the problem on a personal basis.

It is also unlikely that the appliance will have value as a status symbol. It will most likely be hidden from view in the home. Although it may be a novelty for a brief period, it seems doubtful that the disposer would be purchased as a conversation piece.

This is not to say that there is no potential market at all for the product, for it has been shown that a great need exists in the area of waste disposal. The problem is that the market is not yet in a form with which Whirlpool is accustomed to dealing.

The second factor that complicates the management process is that there are several forces, which are not under Whirlpool's direct control, that could have a great influence on the success or failure of this new product venture. The first of these forces is the general public, a force over which industry has gained some control through advertising and marketing techniques. This is usually the main force outside the industry with which managers must deal when marketing a product. In this case, however, there are two additional important outside forces. There is the source of the waste problem; that is, any industry, such as the packaging or newspaper industries, that produces a product which ultimately becomes refuse in the household. This is the force that determines, to a great extent, the magnitude of the disposal problem for a given household unit. In other words, these industries help to create the problem which Whirlpool's product is to solve. The other outside force is the government at local, state, and national levels. The government is a factor due to its realization of the disposal problem and its power to apply pressure in various places in attempts to solve the problem.

The importance of these various factors will be developed more thoroughly in the Literature Survey of this thesis. For the present, they can be visualized as elements of a large system of which Whirlpool is also an element. These elements are constantly interacting and influencing each other. Whirlpool must operate within this complex dynamic system. Managers must make decisions and take actions which will affect the behavior of the entire system, thereby affecting Whirlpool's position within the system.

Typically the position of a manager in a feedback system may be described as shown in Figure 1. The manager attempts to separate himself from the rest of the system. He monitors the results produced by the system and compares these results to some desired goals. He then takes

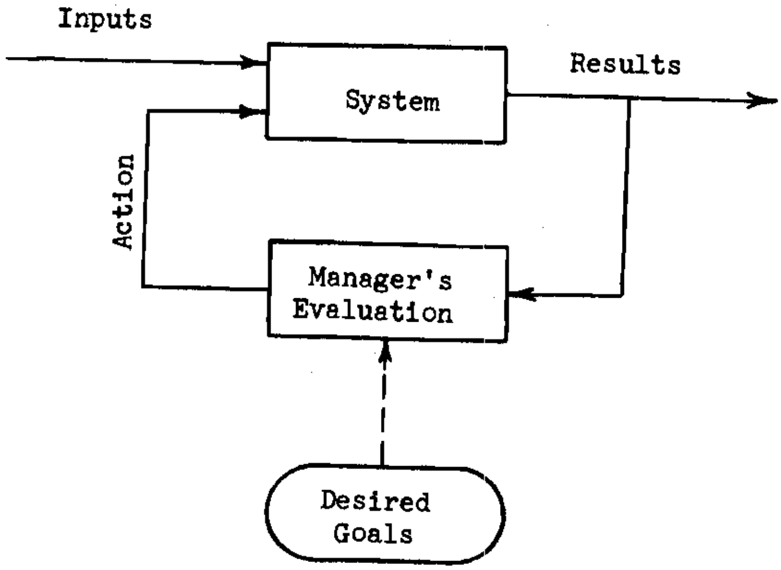

Figure 1. The Typical Management Position.

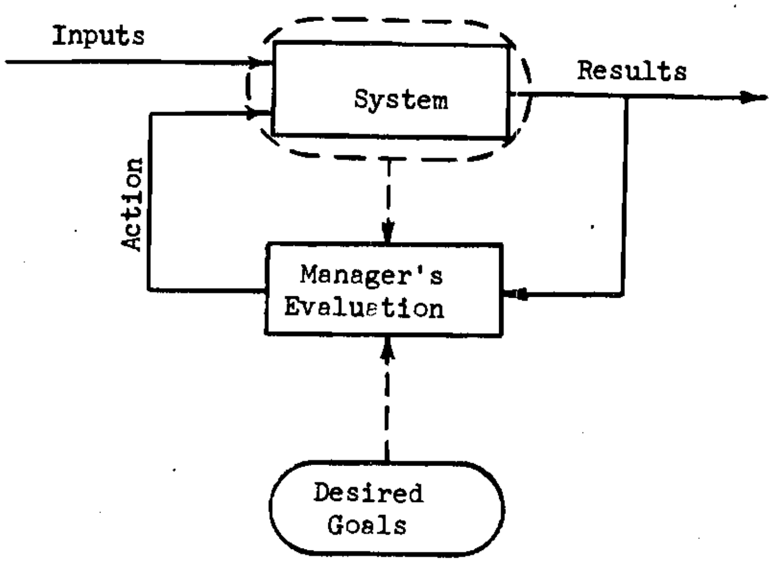

Figure 2. The Improved Management Position.

some action which he hopes will bring the system results into closer alignment with his desired goals.

It is the general objective of this research to add a new dimension to the management function. The improved position of management is shown in Figure 2. The new information which is shown flowing from the system to the manager represents the manager's understanding of the behavioral characteristics of the system. This understanding enables the manager to perceive what causes the system to behave as it does under various conditions. With the new information, the manager should be able to formulate more effective and reliable decision policies. This advances the management function from that of reacting to the system to that of having some real control over the system. In the words of Jay. W. Forrester, management science should provide "...a platform from which to reach further by the exercise of management intelligence and judgment." (2, p. 9)

The general method of approach selected for this study, due to the magnitude and complexity of the system is digital computer simulation. Experiments with a mathematical model of the system will aid in developing the needed understanding of the real world system dynamics and will provide an opportunity to test system behavior under alternate decision policies. The only assumption required is that it is possible to construct a quantitative model of the system which is structurally realistic and which displays dynamic characteristics similar to those of the real system. The plan of attack will be outlined in greater detail in the Procedure.

Note that the objective stated above makes no mention of predicting future events or of optimizing the system or any part of the system. Therefore, precision, not numerical accuracy, is the basic requirement for the structure of the model (2, p. 57). In order to optimize or predict, one would need perfectly reliable data, so that he could establish the correct relationships between every factor that affects the system in any way. In studying system dynamics, however, there is need to include only those factors and relationships which are effective in controlling the system (2, pp. 210-211). Many of the relationships which are of greatest interest are of an intangible nature, and it is impractical, if not impossible, to gather data in order to establish these relationships with accuracy. In such cases, the precision of the model is maintained by establishing the relationships emperically using the best knowledge available. As Forrester has said, "To omit such variables is equivalent to saying that they have zero effect--probably the only value that is known to be wrong!" (2, p. 57)

Note also that it is not the objective of this research effort to contribute to the design of the trash disposal appliance or to recommend a general mode of operation for the device. It will be assumed in the model of the system that an effective and reasonably reliable appliance can be designed, and that it will, in fact, aid in the trash disposal function.

CHAPTER II

LITERATURE SURVEY

A search of the literature shows that although much has been written about the various factors within the system, no effort has been made to relate them to each other in a quantitative or even qualitative model. Therefore, the approach taken in the literature search was to investigate how each of the various system elements, including the government, waste-producing industries, the general public, and Whirlpool's management structure, may exert forces on other elements within the system. With these individual relationships firmly established, the next step was to synthesize them into a conceptual or qualitative model from which a quantitative simulation model could be built. Both of the above steps are presented in this survey.

The Relevant System Elements and Their Importance

The Public

The effect of the general public will first be considered as it relates to the cause of the solid waste problem. The population of the United States is now estimated at slightly over 200 million, and it grew by 8.8 per cent from 1960 to 1965 (11, p. A-4). In addition, the effective retail buying power of the average American household increased by 18.8 per cent during the same period of time (11, p. C-2). These two trends acting simultaneously are naturally contributing to the great increases in both the total production and the per capita production of waste in the nation. Of the four pounds of refuse that is produced each day for each person in the United States, approximately 3.2 pounds come from households (3).

Furthermore, the public must be considered as it relates to the success of Whirlpool's proposed product. If the public is to buy the product, the individual household units must first feel the need for the product. As has been pointed out earlier, the public has not yet felt this need on a personal basis. The reason is that the problem is growing faster on a national level, due to the increase in population, than it is on a per capita or household level. In addition, the majority of people in urban areas have some refuse removal service provided for a price which they do not realize they are paying through their local taxes.

If and when the need is felt for such a disposal appliance, the public will have another hand in determining the success or failure of Whirlpool's product. The public will either accept the product or reject it in favor of some other alternative.

Sources of Waste

Any industry producing a product, any part of which ultimately becomes waste in the household, will be referred to hereafter as a source industry. By far the most significant members of this group are the packaging industry and the newspaper industry. The source industries play a large part in determining the magnitude of the solid waste problem on the per capita level and the national level. Through changes in materials and methods, these industries could either help solve the problem at its source, or by acting in the opposite direction, they could compound the problem to an intolerable level. The decision between these two courses of action is of vital importance to Whirlpool, for Whirlpool could hardly market a product which is meant to alleviate a problem that no longer exists.

A survey of the past performance of the source industries shows a steady trend in the direction of compounding the problem. Many cans are now made of rust-proof aluminum. Plastic packaging has also become very popular, but Von Kanman Center's study on waste-management explains that plastics are:

> ...almost completely immune to biological decomposition. If we bury them, they remain almost indefinitely in their original state. If we burn them, they contribute hydrocarbons and oxides of nitrogen to our atmosphere (4).

Non-returnable bottles and the general increased use of glass have also contributed to the problem. Paper, however, still ranks first as the most common form of refuse, for the average American uses 457 pounds of it each year (4).

The outlook for the future appears much the same. There is an ever increasing emphasis in the packaging industry on the marketing value of attractive and durable packaging (5). The industry is seeking to appeal to all the human senses through the artistic use of color, shape, and texture (15). In the future, the public may expect to see textured nylon dresses packaged in small cans to demonstrate the wrinkle resistant qualities of the material (6, p. 58). Cooking oil may be packaged in rectangular gallon cans similar to those used presently for such products as mineral spirits (6, p. 29). New technological developments will allow the metal cans of tommorow to be contoured to increase their appeal to the eye and the touch (7). The recent popularity of cellophane bags is expected to lead to the use of aluminum foil pouches for many packaging jobs (8). The packaging industry is of necessity developing more exotic, decorative, and durable packaging techniques, many of which will result in increased waste disposal problems.

The apparent trends, however, do not indicate a complete lack of awareness or concern over the waste problem on the part of the source industries. A questionnaire was sent to 14 of the leading packaging companies in the United States. A sample questionnaire is shown in Appendix A along with a list of the companies to which the questionnaires were sent. Of the ten that responded, every one indicated an awareness of the problem on the part of their company. Six of the companies reported that they were either engaged in or supporting research to develop materials or techniques that would help alleviate the waste problem, although the waste problem was not the primary motivation for the research in some cases. Some of the developments under study indicate accelerated aging paper, paper or cardboard cans to replace metal cans and plastic bottles, and cartons which can be defibered after use so that they can be reused as secondary fiber in producing new cartons. One of the most significant prospects for improvement is the new emphasis on the design of packages that can be of functional value to the consumer after it has served as a package. One example is a package for picnic charcoal which serves as a starter for the fire (12). Another development to help alleviate the problem is a bottle that begins to decompose as soon as the top is removed (9).

In general, the source industries realize the existence of the waste problem and have demonstrated some ability to help solve it. These industries, however, react to the pressures that they experience from their market and their environment. The pressure from their market to produce creative packaging with marketing value is so much greater than the pressure from their environment to cut back the source of waste, that any advancement along the lines of preventing waste would most probably be coincidental at this time. This is not to say that the relative magnitudes of these pressures cannot change in the future.

The Government

It was stated in the introduction that the government at local, state, and national levels is an important element in the system due to its realization of the solid waste problem and its power to apply pressure in various places in an attempt to solve the problem. The government's awareness of the problem is attributable to the fact that it is the agency traditionally charged with the responsibility of waste collection and disposal. The government has felt the full impact of the increasing population as it relates to the magnitude of the disposal problem.

The concern of the federal government was manifest in 1965, when Congress passed The Solid Waste Disposal Act. The stated purposes of the Act are to encourage and help support research on the problem and to give financial and technical assistance to lower level agencies in the planning, development, and conduct of solid waste disposal programs.

There are two ways in which the government may apply pressure in attempts to solve the solid waste problem.

First, the federal government may legislate restrictions on the source industries in order to eliminate waste before it is created. The Public Health Service has already recommended research on " ...development of soluble or degradable containers..." and the " ...feasibility of legal restrictions on nonreturnable containers, junk mail, etc. ..." (14, p. 4).

Second, the government at any level may require that the public install and use some disposal device in their residences or other buildings. These requirements may take the form of local building codes or specifications on buildings that are totally or partially financed by local, state, or the federal government. The Public Health Service has recognized the value of waste disposal at the point of origin, especially since an estimated 85 per cent of the cost of the waste disposal function is spent on the collection of the refuse (13). At the same time, however, the Public Health Service stresses the need for such disposal devices to provide capacity today to meet the anticipated needs and improved standards of tomorrow, and to do so at a reasonable cost (14, p. 11).

There are numerous precedents for these two types of legislation, especially with regard to air and water pollution, automotive safety, food and drugs, and public sanitation.

The Whirlpool Management Structure

The management at Whirlpool must first perceive the potential market that exists for their proposed product. As time passes this perception will change. It will be colored by pressures that Whirlpool will observe to be developing in other sectors of the system, such as in the government or source industries. These pressures may affect Whirlpool's perception of the market before they affect the market itself. That is to say that the Whirlpool management will attempt to forecast the effects these developments will eventually have on the market.

This perception of market potential will be converted through decision policies into action to control the development and marketing of the product. Decisions must be made with regard to the resources to be devoted to development effort and to sales effort.

The development and marketing efforts will in turn have effects on the other sectors of the system. By developing the capability of the disposal device, Whirlpool will tend to relieve the alarm of the government and the source industries over the problem, since a solution to the problem will appear to be eminent. The capability of the product along with the sales effort will affect the attitude of the general public toward the product and its desirability.

The Conceptual Model

The conceptual or qualitative model of the system can now be constructed by synthesizing the relationships between the various factors as discussed above. The conceptual model is shown in Figure 3. Each

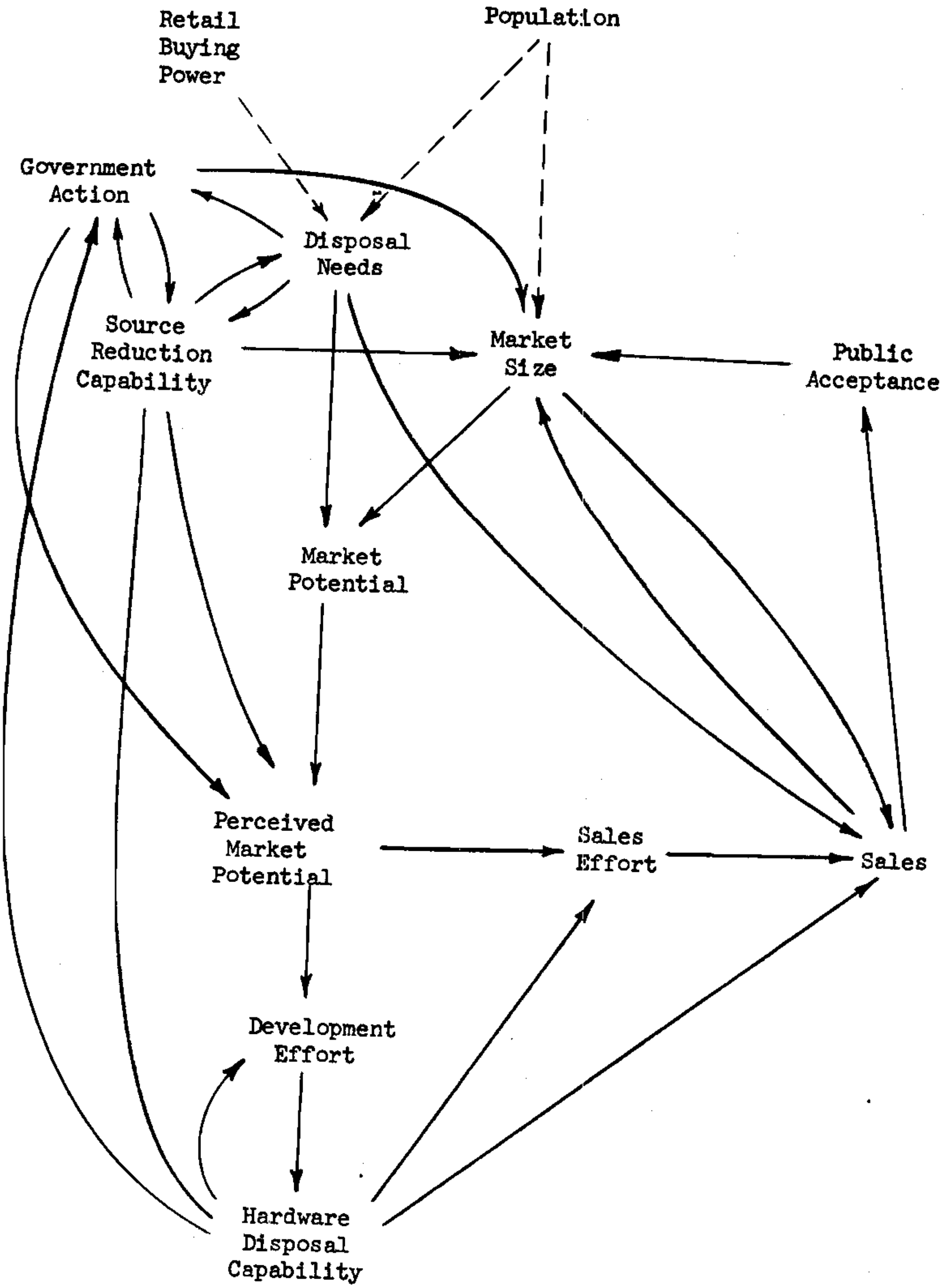

Figure 3. The Conceptual Model.

arrow represents a causal relationship or a flow of information from the factor at the tail end of the arrow to the factor at the head end. Feedback loops may be identified as closed paths of causal relationships which pass through each factor along their paths exactly one time. There are 26 such feedback loops within the system. The dotted arrows indicate that "Retail Buying Power" and "Population" are exogenous factors. These two factors affect the system, but are not affected by the system. Therefore, these factors are not contained within any feedback loops. The term "Source Reduction Capability" refers to the ability of the source industries to reduce the amount of waste created per capita. "Hardware Disposal Capability" refers to the ability of Whirlpool's disposal device to effectively dispose of trash.

CHAPTER III

PROCEDURE

The Plan of Attack

The research was carried out in a series of fairly distinct steps. The entire procedure is described below:

(1) The specific problem was identified and system boundaries were established at the appropriate level for the study.

(2) The elements that were believed to be of importance within the system were isolated, and their importance was documented.

(3) A conceptual model of cause-and-effect feedback loops was constructed involving the elements that were isolated in step 2.

(4) A mathematical model corresponding to the conceptual model was constructed.

(5) System behavior was simulated through time. The behavior of the model was compared with behavior which seems reasonable for the real world system. The model was run in sections at a time in order to make these comparisons more effectively. The model was restructured wherever discrepancies appeared to exist. This process was repeated until the entire model had been validated as realistic.

(6) The model was analyzed to determine what factors and feedback loops play the greatest parts in determining system behavior as time passes.

(7) The model was tested under alternative system structures and

decision policies to determine how Whirlpool can effectively exercise the greatest degree of control over the entire system.

(8) The results of the model experiments were related back to the real world system, and their implications were discussed.

The Modeling Language

The DYNAMO computer language was used in modeling the system. There are several reasons for the selection of DYNAMO for this study.

(1) It provides for feedback characteristics.

(2) It provides for delays in actions.

(3) It provides for complex nonlinear relationships.

(4) It is easy to program, analyze, and revise.

(5) Results can be easily interpreted by a person who is unfamiliar with the language itself.

(6) Great computational speed provides efficient and economical computer usage.

Data for the Model

The data which were used in establishing the parameters of the model were collected mainly through appropriate literature and interviews with company officials. It was necessary to set some parameters strictly by subjective estimation due to lack of better information, but when this was done, the model was tested for sensitivity to the estimated parameters.

CHAPTER IV

MODEL FORMULATION

The quantitative simulation model written in DYNAMO will be presented in this chapter. Chapters six through nine of Jay W. Forrester's Industrial Dynamics and sections 1.1 through 1.4 in chapter one of Alexander L. Pugh's Dynamo User's Manual are suggested as preparatory material for the reader who is unfamiliar with the DYNAMO language.

General Description

The computational time interval "DT" is defined in the model as one month. Each simulation run has a length of 360 months or 30 years in simulated time. The values of plotted variables were shown on every fourth month.

The model is made up of eleven sectors, which generally correspond to the areas shown on the conceptual model. Each sector will be presented separately. The equations will be explained and a flow diagram will be shown for each sector. The identifiers that are used in the equations will be explained the first time they are used in every sector. The entire model is shown in flow diagram form in Appendix B along with a complete alphabetical list of identifiers and their explanations.

Population, Families, and Retail Buying Power

The population of the United States is represented as a level that grows by a constant percentage each month. Note that the rate of change in population is the net growth and not simply the birth rate.

```
POP.K=POP.J+(DT)(POPGR.JK+0)
POPGR.KL=(APMIP)(POP.K)
APMIP=0.0014
```

POP - POPulation (thousands of people)
POPGR - POPulation GRowth (thousands of people/month)
APMIP - Average Percentage Monthly Increase in Population (dimensionless)

The number of families is important in the model, since a family represents a potential member of the market for a trash disposal device. The rate of growth of the number of families is determined by dividing the rate of growth of population by the average number of people in a family and then delaying the rate by 240 months or 20 years to allow the potential family to reach adulthood.

```
CF.K=CF.J+(DT)(CFGR.JK+0)
CFGR.KL=DELAY#(PFGR.JK,DRA)
DRA=240
PFGR.KL=POPGR.JK/AFS
AFS=3.4
```

CF - Current Families (thousands of families)
CFGR - Current Family GRowth (thousands of families/month)
PFGR - Potential Family GRowth (thousands of families/month)
DRA - Delay in Reaching Adulthood (months)
AFS - Average Family Size (people/family)

The effective retail buying power of the public is also represented as a level that increases by a constant percentage. At time zero, the level is given the index value of one.

```
RBP.K=RBP.J+(DT)(CRBP.JK+0)
CRBP.KL=(AMIBP)(RBP.K)
AMIBP=0.003
```

RBP - Retail Buying Power (dimensionless)
CRBP - Change in Retail Buying Power (1/month)
AMIBP - Average Monthly Increase in Retail Buying Power (dimensionless)

The flow diagram for this sector appears in Figure 4.

Daily Disposal Needs

The number of pounds of refuse to be disposed of each day in the United States is equal to the population multiplied by the waste produced in pounds per person each day. The waste produced per capita is calculated as the product of a normal waste coefficient and two multiplying effects.

The first effect is the impact of the public's effective retail buying power. The impact ranges from 1.0 to 1.5 as retail buying power increases from its initial value. The graphical relationship is shown in Figure 5. The second effect on the waste produced per capita is source reduction capability, which ranges in value over the non-negative real numbers. A value of zero for source reduction capability would indicate that the source industries had eliminated all potential waste, whereas the value one is the index which indicates the state of source reduction capability at time zero.

```
DDN.K=(POP.K)(WPPC.K)
WPPC.K=(WC)(IRBPW.K)(SRC.K)
WC=3.2
IRBPW.K=TABHL(TIRBP,RBP.K,1.0,2.5,0.25)
TIRBP*=1.00/1.13/1.24/1.34/1.43/1.48/1.50
```

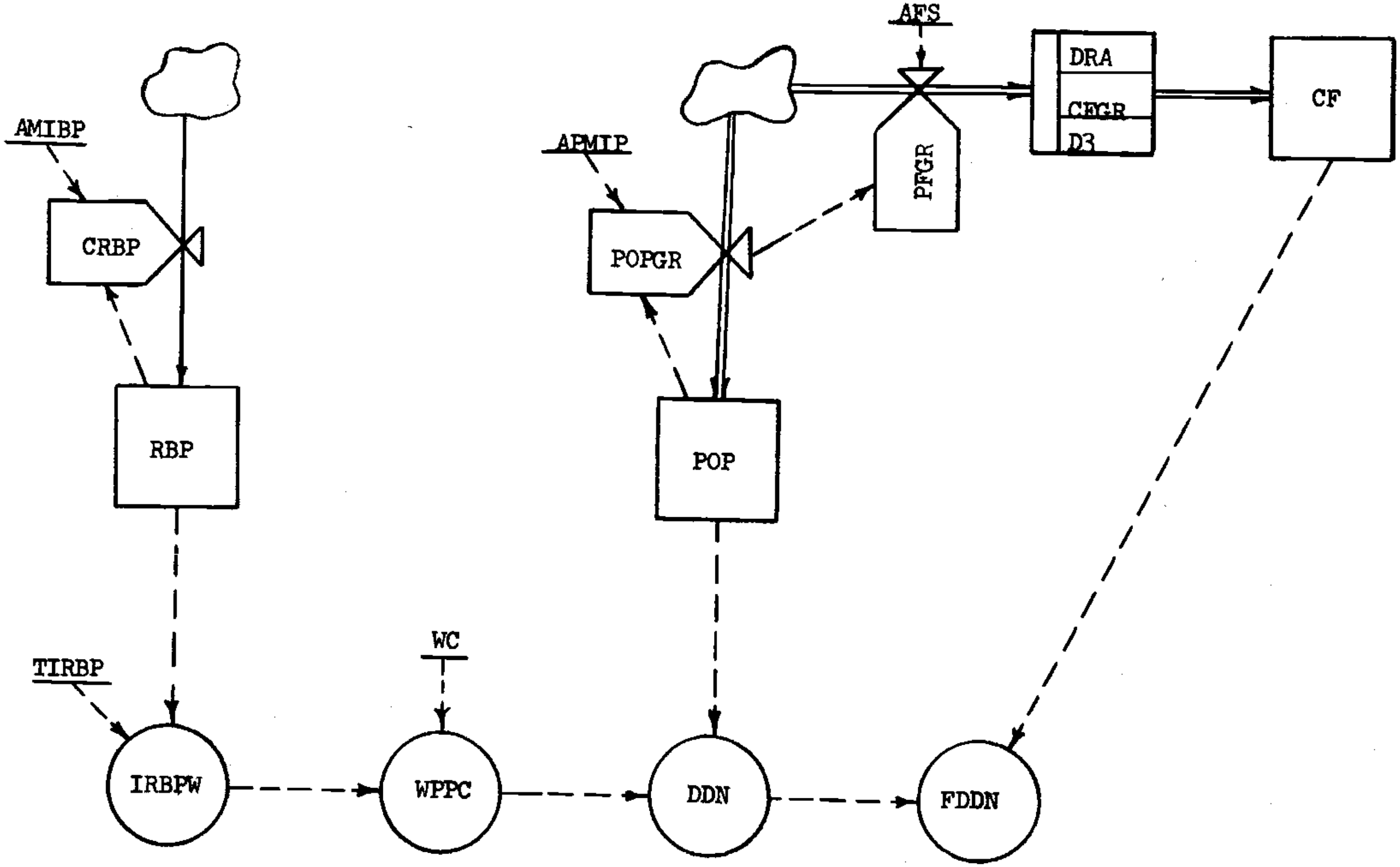

Figure 4. Population, Families, and Retail Buying Power.

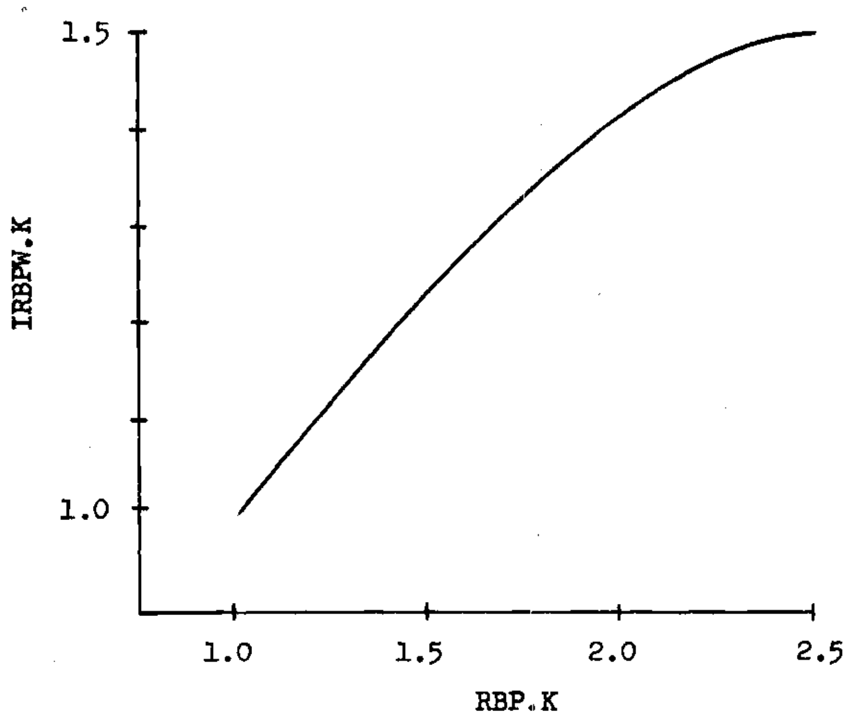

Figure 5. IRBPW Versus RBP.

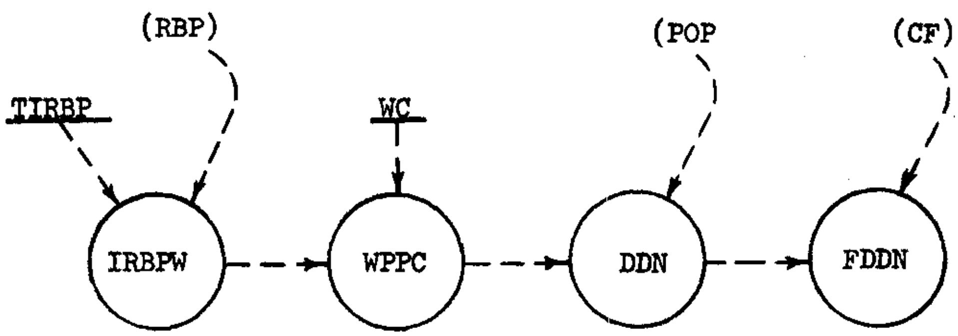

Figure 6. Daily Disposal Needs.

DDN - Daily Disposal Needs (thousands of pounds/day)
POP - POPulation (thousands of people)
WPPC - Waste Produced Per Capita (pounds/person/day)
WC - Waste Coefficient (pounds/person/day)
IRBPW - Impact of Retail Buying Power on Waste (dimensionless)
TIRBP - Table of IRBPW versus RBP - Figure 5
RBP - Retail Buying Power (dimensionless)

The daily disposal needs for one family is simply the total daily disposal needs of the entire nation divided by the number of families in the nation.

FDDN.K=DDN.K/CF.K

FDDN - Family Daily Disposal Needs (pounds/family/day)
CF - Current Families (thousands of families)

Figure 6 shows the flow diagram for this sector of the model.

Government Reactions

There are two forms of government reaction which may be manifest simultaneously. The first reaction is the government's alarm over the waste disposal problem. Three multiplying effects determine the magnitude of this alarm. The first is the impact of daily disposal needs. The relationship between daily disposal needs and its impact on government alarm is shown in Figure 7. Figure 8 shows the impact of source reduction capability on government alarm. The impact varies directly with the magnitude of source reduction capability, since the higher the numerical value of source reduction capability, the greater is the waste problem due to source industries. The final effect is the impact of the

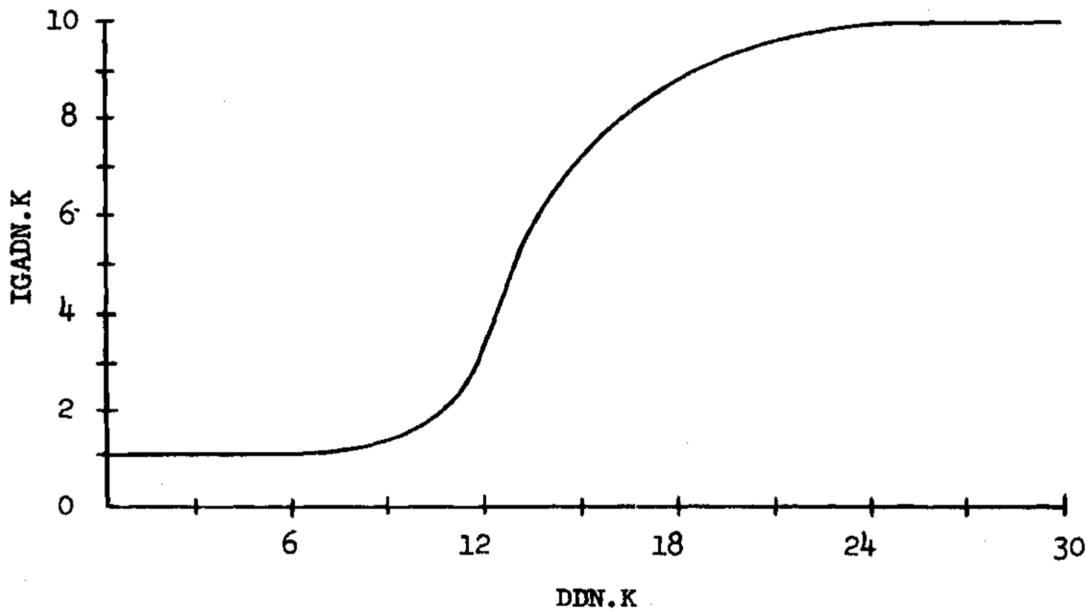

Figure 7. IGADN Versus DDN.

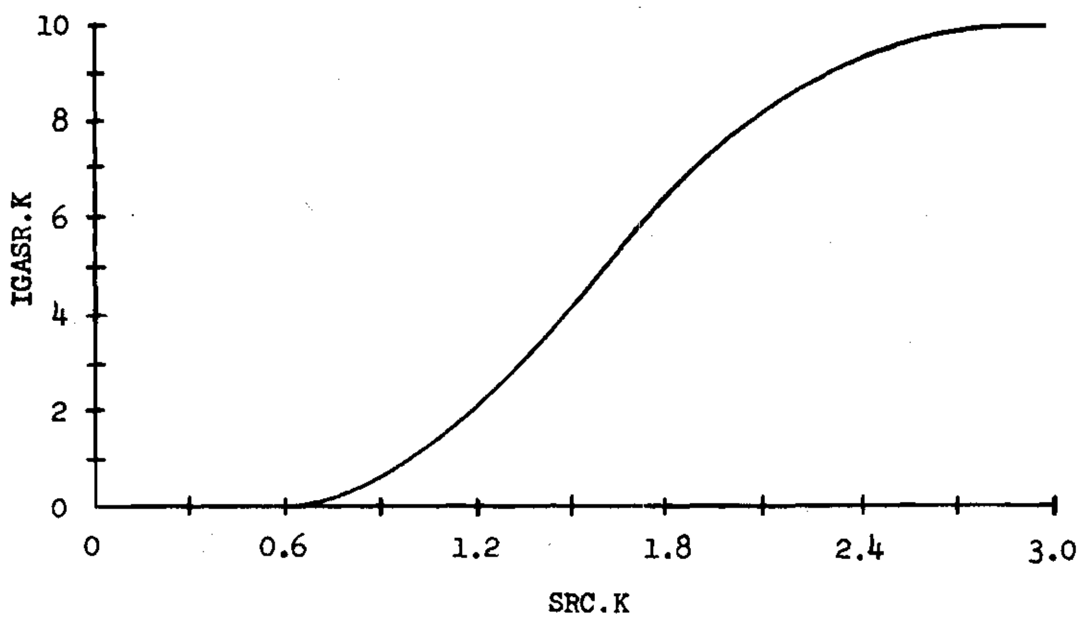

Figure 8. IGASR Versus SRC.

hardware capability of Whirlpool's trash disposal appliance. A value of one for this capability indicates the ability to completely destroy all trash, whereas the value zero indicates no trash disposal capability at all. This impact is shown in Figure 9. The relationship is inverse, since the government would view the hardware capability as a potential solution to the waste disposal problem. The product of these three impacts may range in value from zero to one hundred and is a dimensionless representation of the government's alarm.

```
GAWDP.K=(IGADN.K)(IGASR.K)(IGAHC.K)
IGADN.K=TABHL(TGADN,DDN.K,600000,3000000,300000)
TGADN*=1/1/5/3.1/7.1/8.8/9.6/9.9/10/10
IGASR.K=TABHL(TGASR,SRC.K,0,3,0.3)
TGASR*=0/0/0/0.5/2.2/4.1/6.5/8.3/9.4/9.9/10
IGAHC.K=TABLE(TGAHC,HDC.K,0,1,0.1)
TGAHC*=1.0/0.97/0.91/0.82/0.71/0.58/0.45/0.32/0.21/
      0.14/0.10
```

GAWDP - Government Alarm over the Waste Disposal Problem (dimensionless)
IGADN - Impact on Government Alarm of daily Disposal Needs (dimensionless)
TGADN - Table of IGADN versus DDN - Figure 7
DDN - Daily Disposal Needs (thousands of pounds/day)
IGASR - Impact on Government Alarm of Source Reduction Capability (dimensionless)
TGASR - Table of IGASR versus SRC - Figure 8
SRC - Source Reduction Capability (dimensionless)
IGAHC - Impact on Government Alarm of Hardware Disposal Capability (dimensionless)
TGAHC - Table of IGAHC versus HDC - Figure 9
HDC - Hardware Disposal Capability (dimensionless)

The second form of government reaction is the government's desire to have trash disposal devices installed and used by the public. This reaction would be expected when the daily disposal needs of the nation

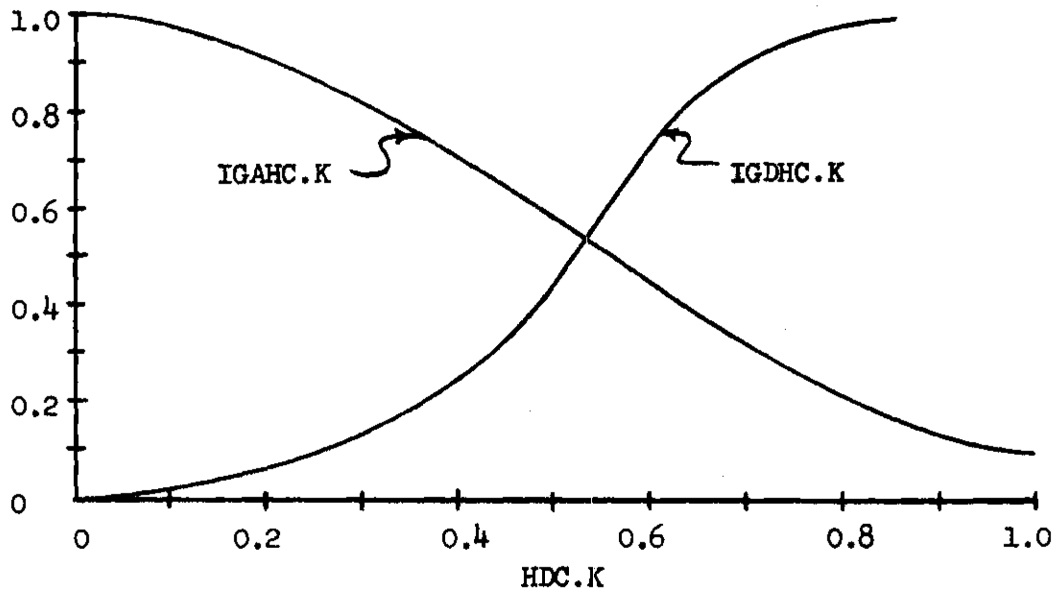

Figure 9. IGAHC and IGDHC Versus HDC.

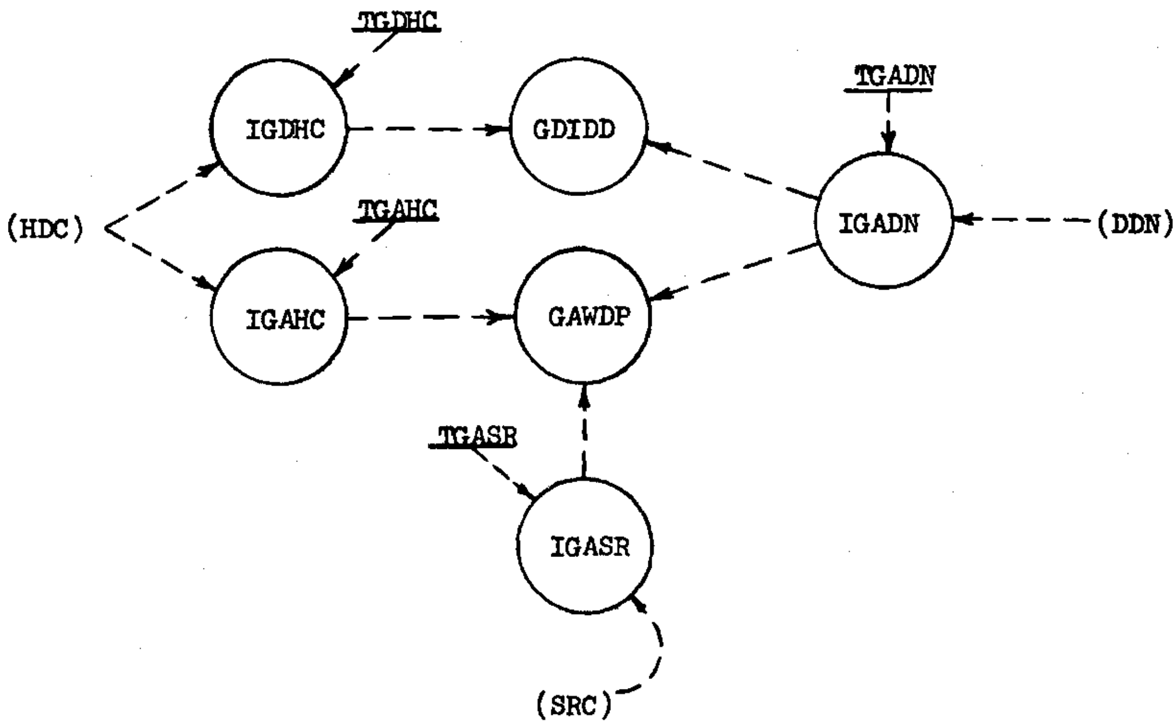

Figure 10. Government Reactions.

have reached an alarmingly high level, and the capability of the disposal device has become highly developed. Therefore, this reaction is calculated as the product of the impact of daily disposal needs, as presented above, and an impact of hardware disposal capability, which is shown in Figure 9. It is seen that the impact of hardware capability is positively sloped when it relates to the government's alarm over the problem. The variable representing the government's desire to implement the disposal devices is dimensionless and its magnitude ranges from zero to ten.

```
GDIDD.K=(IGADN.K)(IGDHC.K)
IGDHC.K=TABLE(TGDHC,HDC.K,0,1,0.1)
TGDHC*=0/.02/.06/.14/.24/.45/.73/.90/.98/1.0/1.0
```

GDIDD - Government's Desire to Implement Disposal Devices (dimensionless)
IGDHC - Impact on Government Desire of Hardware Capability (dimensionless)
TGDHC - Table of IGDHC versus HDC - Figure 9

The flow diagram for the government reactions sector is shown in Figure 10.

Market Size

Market size is a measure of the number of household units in the nation that are interested in an financially able to buy a trash disposal device. For simplicity's sake, the terms household unit and family will be considered as synonymous. The market size is structured as a level which is affected by five rates of flow.

```
MS.K=MS.J+(DT)(GMS.JK-RMS.JK-SALES.JK+GMSWO.JK+GMSGA.JK+O)
```

MS - Market Size (thousands of families)
GMS - Growth in Market Size (thousands of families/month)
RMS - Reduction in Market Size (thousands of families/month)
SALES - SALES (thousands of families/month)
GMSWO - Growth in Market Size due to Wear Outs (thousands of families/month)
GMSGA - Growth in Market Size due to Government Action (thousands of families/month)

The first rate, growth in market size, is due to the general desirability of the product and its acceptance by the public. The rate is represented as the number of families which have not yet entered the market divided by a delay in entering the market. This delay is a variable which depends on a normal average value of 300 months affected by the change in source reduction capability that the public has experienced in the recent past and by the public's acceptance of the product. The average delay of 300 months may initially seem rather large, but there are two reasons for its magnitude. First, it must be remembered that some of the families in the nation will never enter the market due to financial reasons. The effective delay for these families is infinitely large. Furthermore, past experience with conventional garbage disposal units has shown that these units are seldom installed except when a new house is being built or an existing kitchen is being remodelled. If the installation of Whirlpool's appliance involves extensive plumbing or electrical work, the trend may be much the same as with conventional garbage disposal units. Therefore, even though a family may be interested in having a disposal appliance, their entrance into the market may be delayed until they decide to build a new home or remodel their kitchen.

```
GMS.KL=(I/DELEM.K)(CF.K-MS.K)
DELEM.K-(EAD)(ICSRI.K)(IPA.K)/((NIESR)(NIPA)(I))
EAD=300
NIESR=1.0
NIPA=1.0
```

```
DELEM - Delay in Entering the Market (months)
CF    - Current Families (thousands of families)
EAD   - Effective Average Delay (months)
ICSRI - Impact of Experienced Change in Source Reduction
        Capability #1 (dimensionless)
IPA   - Impact of Public Acceptance (dimensionless)
NIESR - Normal Impact of Experienced Change in Source
        Reduction Capability (dimensionless)
NIPA  - Normal Impact of Public Acceptance (dimensionless)
```

The experienced change in source reduction capability is computed as the difference between the present source reduction capability and a value of source reduction capability which has been exponentially smoothed over the past three months. The relationship between this experienced change and its impact on the delay in entering the market is shown in Figure 11. When the experienced change is zero, the impact assumes its normal value of one. If the change is positive, indicating a worsening of the problem, the impact is less than one thereby decreasing the delay. When the change is negative, the impact increases the delay.

```
ICSRI.K=TABHL(TISRI,ECSRC.K,-0.05,0.05,0.01)
TISRI*=3.0/2.94/2.68/2.14/1.30/1.0/0.84/0.73/0.64/0.56/0.50
ECSRC.K=SRC.K-SSRC.K
SSRC.K=SSRC.J+(DT)(L/DSSRC)(SRC.J-SSRC.J)
DSSRC=3
```

```
TISRI - Table of ICSRI versus ECSRC.K - Figure 11
ECSRC - Experienced Change in Source Reduction Capability
        (dimensionless)
SRC   - Source Reduction Capability (dimensionless)
SSRC  - Smoothed Source Reduction Capability (dimensionless)
DSSRC - Delay in Smoothing Source Reduction Capability (months)
```

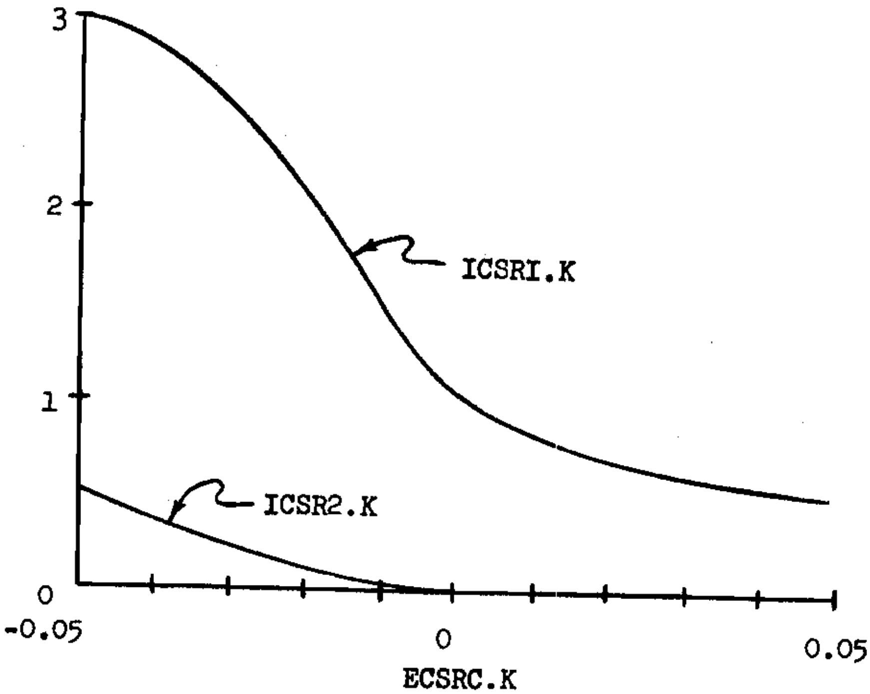

Figure 11. ICSRI and ICSR2 Versus ECSRC.

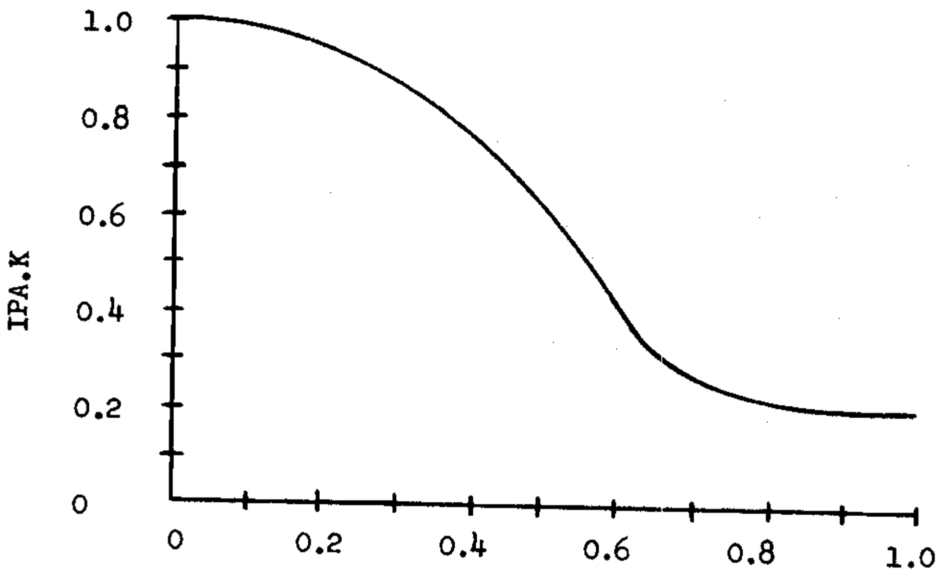

Figure 12. IPA Versus PA.

The impact of public acceptance on the delay in entering the market is shown in Figure 12. Public acceptance is measured from zero, indicating no acceptance, to one, indicating full acceptance. When public acceptance is zero, its impact on the delay is one, the normal value. As public acceptance grows, the impact becomes less than one, thereby decreasing the delay in entering the market.

```
IPA=TABLE(TIPA,PA.K,0,1.0,0.1)
TIPA*=1.0/0.99/0.95/0.89/0.78/0.62/0.43/0.29/0.22/0.20/0.20
```

```
IPA    - Impact of Public Acceptance (dimensionless)
TIPA   - Table of IPA versus PA - Figure 12
PA     - Public Acceptance (dimensionless)
```

The second rate affecting the market size is the reduction in market size. This rate is due entirely to negative experienced changes in source reduction capability, which give the public reason to believe that the waste problem is being solved by the source industries. The rate of reduction in market size is calculated as the product of a fractional impact due to the change in source reduction capability, and the present market size. The impact, illustrated in Figure 11, shows that the larger the negative change in source reduction capability, the larger will be the fractional reduction in market size.

```
RMS.KL=RECSR.K
RECSR.K=(ICSR2.K)(MS.K)
ICSR2.K-TABHL(TISR2,ECSRC.K,-0.05,0,0.01)
TISR2*=0.5/0.35/0.22/0.12/0.04/0
```

RECSR - Reduction in Market Size due to Experienced Change in Source Reduction Capability (thousands of families/month)
ICSR2 - Impact of experienced Change in Source Reduction capability #2 (dimensionless)
TISR2 - Table of ICSR2 versus ECSRC - Figure 11

Sales is included as a rate affecting market size, since the sale of an appliance removes from the market the family that purchased the appliance.

The fourth rate, growth in market size due to wear out, represents those families who re-enter the market for a new appliance after an appliance, which was purchased earlier, has worn out. This rate is a third order delay of the sales rate with an average wear out delay of 120 months or ten years.

```
GMSWO.KL=DELAY3(SALES.JK,DELWO)
DELWO=120
```

DELWO - DElay to Wear Out (months)

The final rate that affects market size is the growth due to government action. This growth is caused by the government's desire to implement disposal devices, which was developed in the sector on government reactions. The government plans an increase in market size which is equal to some fraction of the families not yet in the market. The fraction is a direct nonlinear function of the desire to implement disposal devices, and it is shown in Figure 13. This planned growth becomes an actual growth after a delay of 24 months or two years.

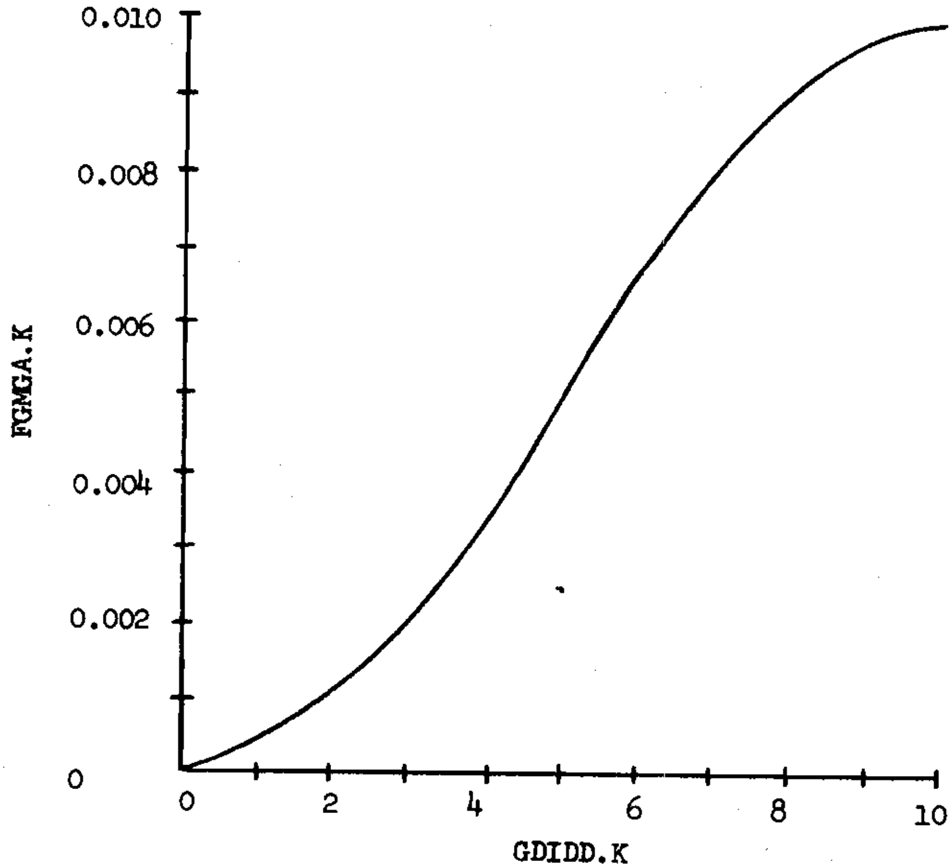

Figure 13. FGMGA Versus GDIDD.

```
GMSGA.KL=DELAY3(PGMGA.JK,DEGA)
DEGA=24
PGMGA.KL=(FGMGA.K)(CF.K-MS.K)
FGMGA.K-TABLE(TFGMG,GDIDD.K,0,10,1)
TFGMG*=0/0.0002/0.0009/0.002/0.0034/0.005/0.0066/0.008/
      0.009/0.0098/0.01
```

PGMGA - Planned Growth in Market Size due to Government Action (thousands of families/month)
DEGA - DElay in implementing Government Action (months)
FGMGA - Fractional Growth in Market size due to Government Action (dimensionless)
TFGMG - Table of FGMGA versus GDIDD - Figure 13
GDIDD - Government Desire to Implement Disposal Devices (dimensionless)

Figure 14 shows the flow diagram of the entire market size sector.

Market Potential

Decisions with regard to the allocation of development effort and sales effort are based on some perception of the potential market for the product colored by the impacts of conditions that are known to exist elsewhere in the system. Market magnitude is a variable which represents the degree of urgency associated with the market. It is calculated simply as the product of market size and family daily disposal needs. The market magnitude is then converted by means of a nonlinear relationship shown in Figure 15 to a measure of market potential, which is dimensionless and ranges from zero to one. Since the management of Whirlpool cannot observe instantaneous changes in family daily disposal needs or in market size, the managers' perceived market potential is an exponentially smoothed value of the actual potential. The delay in perceiving market potential is estimated as six months.

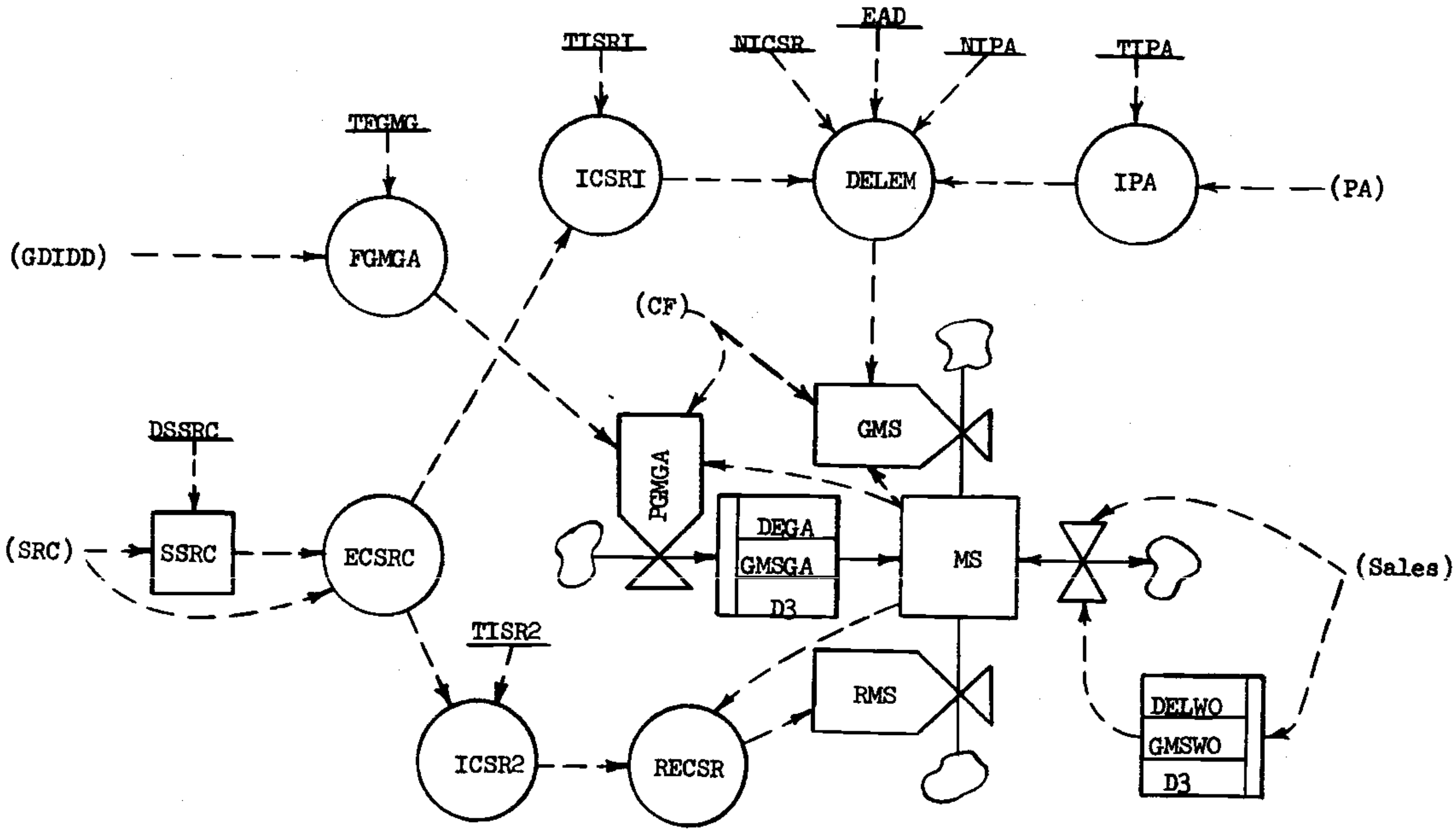

Figure 14. Market Size.

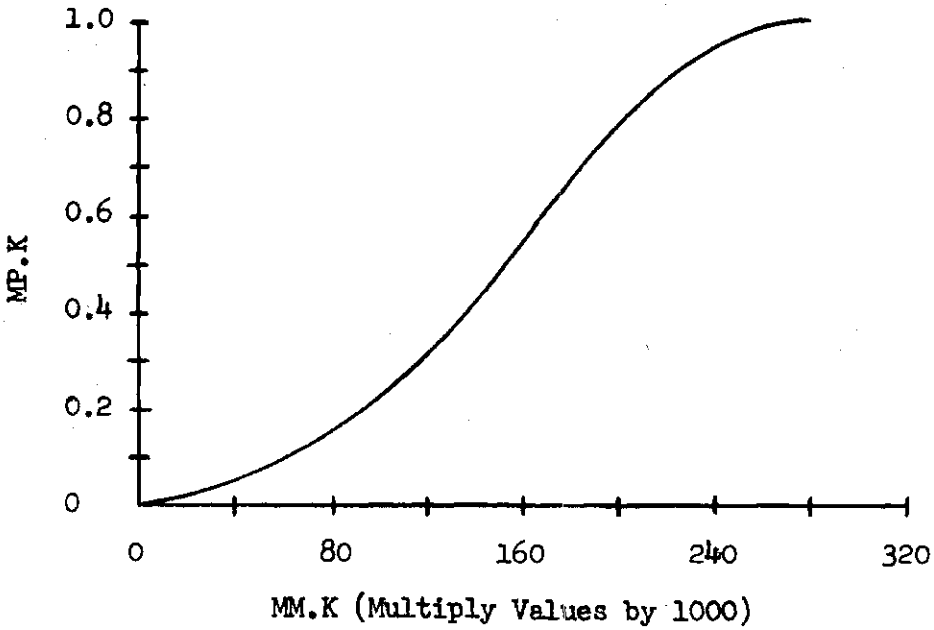

Figure 15. MP Versus MM.

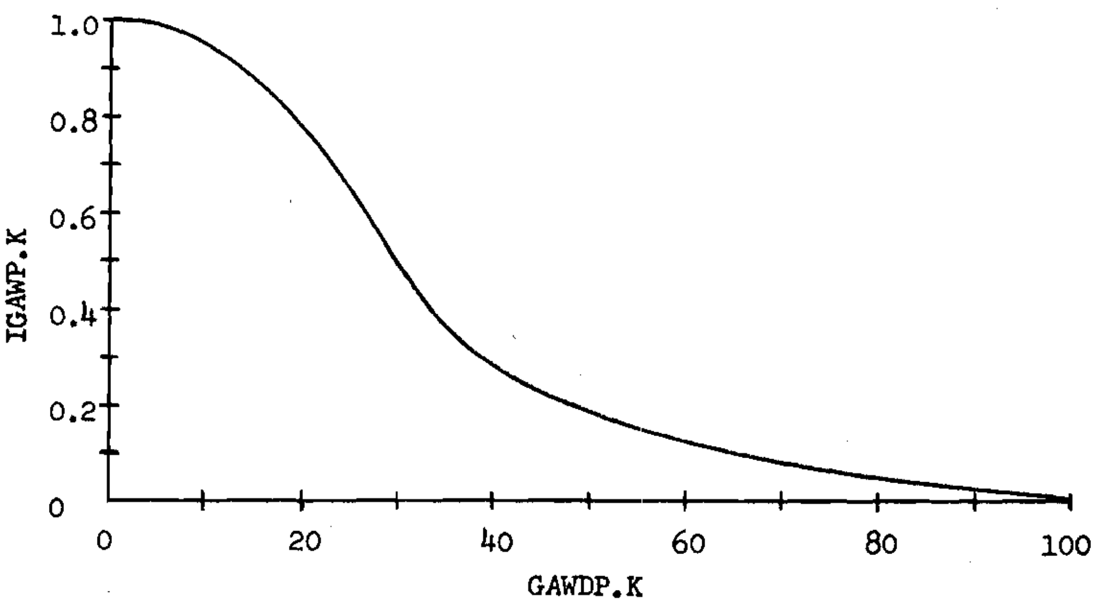

Figure 16. IGAWP Versus GAWDP.

```
MM.K=(MS.K)(FDDN.K)
MP.K=TABHL(TMP,MM.K,0,300000,200000)
TMP*=0/0.01/0.03/0.08/0.14/0.22/0.31/0.42/0.53/
     0.66/0.78/0.88/0.95/0.99/1.0/1.0
PMP.K=PMP.J+(DT)(I/DPMP)(MP.J-PMP.J)
DPMP=6
```

MM	- Market Magnitude (thousands of pounds/day)
MS	- Market Size (thousands of families)
FDDN	- Family Daily Disposal Needs (pounds/family/day)
MP	- Market Potential (dimensionless)
TMP	- Table of MP versus MM - Figure 15
PMP	- Perceived Market Potential (dimensionless)
DPMP	- Delay in Perceiving Market Potential (months)

As was mentioned earlier, the perception of market potential is colored by the impacts of conditions that are known to exist elsewhere in the system. The first impact is due to the government reactions. The impact attributable to government alarm over the waste problem, Figure 16, is negatively sloped, since the greater the alarm, the greater will be the pressure applied by the government to the source industries to find alternate ways to solve the problem. The impact due to the government's desire to implement disposal devices, Figure 17, is positively sloped, since the desire will eventually lead to an increased market size. The product of these two impacts constitutes the next impact due to government reactions on colored perceived market potential. The final impact is due to experienced changes in source reduction capability as shown in Figure 18. For negative changes, indicating progress toward solving the problem, the impact is less than one. For positive changes, indicating a worsening of the problem, colored perceived market potential is the indicator to which the managers ultimately react.

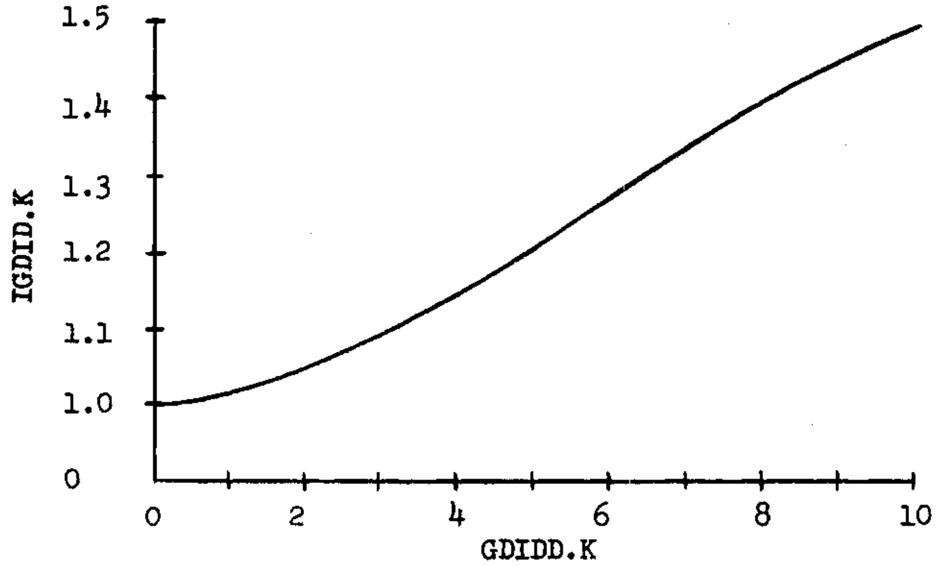

Figure 17. IGDID Versus GDIDD.

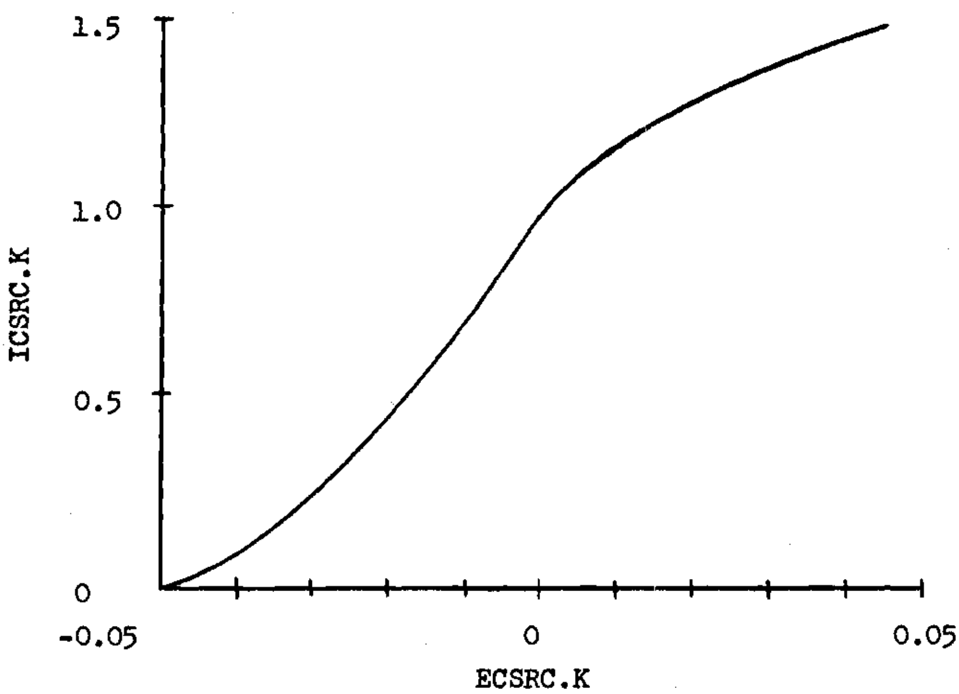

Figure 18. ICSRC Versus ECSRC.

```
CPMP.K=(PMP.K)(IGPMP.K)(ICSRC.F)
IGPMP.K=(IGAWP.K)(IGDID.K)
IGAWP.K=TABLE(TIGAP,GAWDP.K,0,100,10)
TIGAP*=1.0/.96/.80/.46/.29/.19/.14/.11/.07/.03/0
IGDID.K=TABLE(TIGDI,GDIDD.K,0,10,1)
TIGDI*=1/1.01/1.05/1.09/1.14/1.20/1.26/1.33/1.39/1.45/1.5
ICSRC.K=TABHL(TICSR,ECSRC.K,-0.05,0.05,0.01)
TICSR*=0.1/0.15/0.26/0.45/0.73/1.0/1.21/1.34/1.43/1.47/1.5
```

CPMP - Colored Perceived Market Potential (dimensionless)
IGPMP - Impact of the Government on Perceived Market Potential (dimensionless)
ICSRC - Impact of the Change in Source Reduction Capability (dimensionless)
IGAWP - Impact of Government Alarm over the Waste Problem (dimensionless)
TIGAP - Table of IGAWP versus GAWDP - Figure 16
GAWDP - Government Alarm over the Waste Disposal Problem (dimensionless)
IGDID - Impact of Government Desire to Implement disposal Device (dimensionless)
TIGDI - Table of IGDID versus GDIDD - Figure 17
GDIDD - Government Desire to Implement Disposal Devices (dimensionless)
TICSR - Table of ICSRC versus ECSRC - Figure 18
ECSRC - Experienced Change in Source Reduction Capability (dimensionless)

The flow diagram for the market potential sector is shown in Figure 19.

Development Effort

Development effort is measured in man-months devoted to research on the disposal appliance. The development effort is planned based on a maximum of five man-months per month and the impacts of the colored perceived market potential and hardware disposal capability.

It should be noted here that the question of accuracy in using five man-months as the maximum development effort per month has no bearing on the validity of the model. It is the percentage of maximum

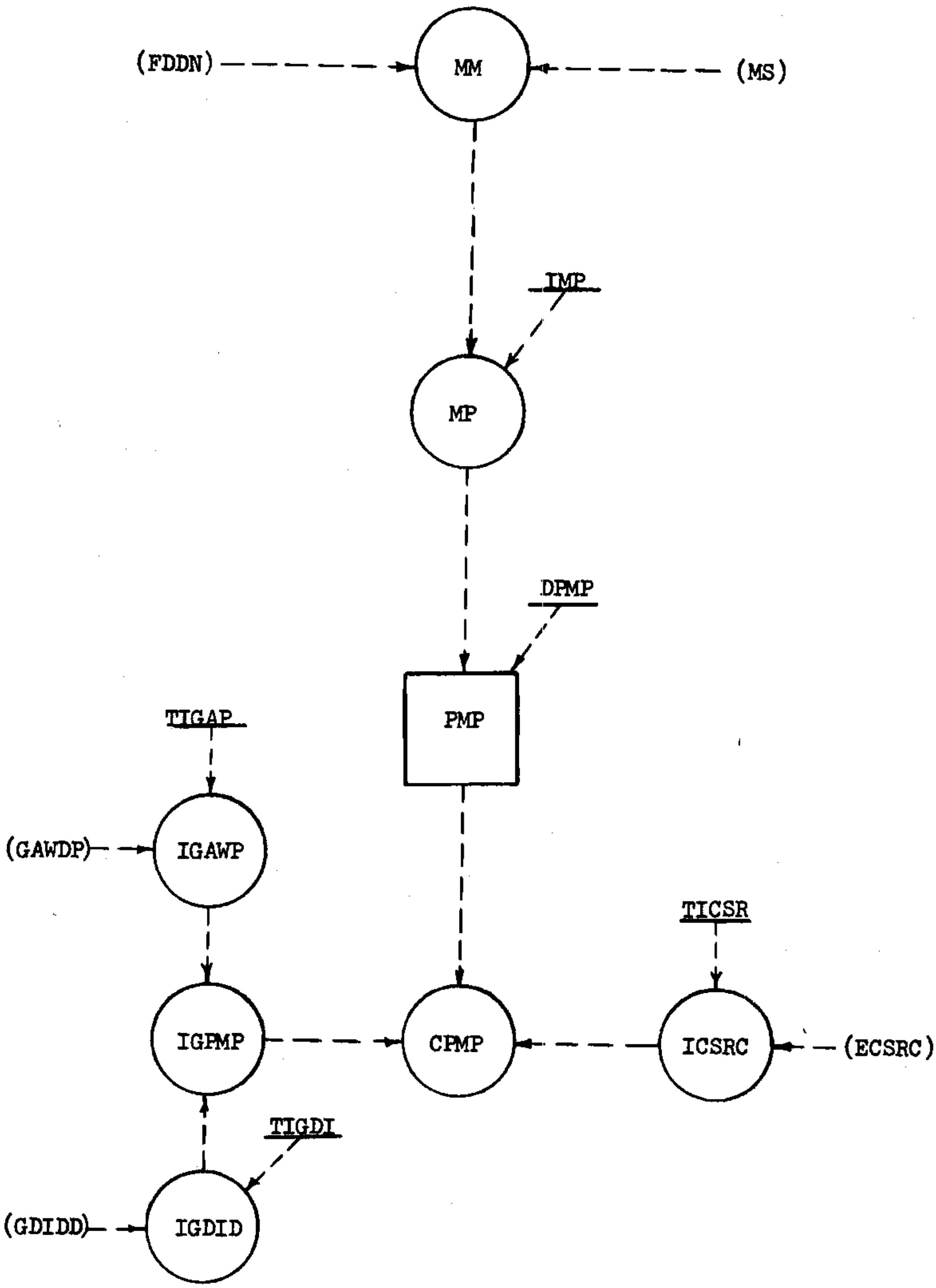

Figure 19. Market Potential.

development effort, not the absolute value of development effort, which is of interest in later computations. Therefore, the maximum development effort could have been defined in any way, as long as all computations involving development effort were consistent with the definition. The use of five man-months per month is meant to add realism and intuitive meaning rather than accuracy to the model.

The impact of colored perceived market potential is shown in Figure 20. It is positively sloped as would be expected.

The impact of hardware disposal capability, Figure 21, is negatively sloped due to a saturation effect. As the product becomes highly developed, the man-power for developmental research would be allocated more profitably on undeveloped products. The impact never reaches zero, since it is assumed that some small amount of development effort would always be devoted to the disposal product no matter how much capability had already been developed. This effort may only serve the purpose of changing the appearance of the product from year to year.

There is a six month delay between the time that the research effort is planned and the time that it is begun.

A cumulative total of development effort is kept for use in the sector on hardware disposal capability.

```
DEF.K=DEF.J+(DT)(CDEF.JK+0)
CDEF.KL=DELAY3(PDEF.JK,DBDEF)
DBDEF=6
PDEF.KL=(MDEF)(LPMP.K)ISHC.K)
MDEF=5
IPMP.K=TABHL(TIPMP,CPMP.K,0,1,0.1)
TIPMP*=0/0.08/0.20/0.33/0.48/0.63/0.76/0.87/0.95/0.99/1.0
ISHC.K=TABHL(TISHC,HDC.K,0.5,1,0.1)
TISHC*=1/0.95/0.81/0.56/0.24/0.1
```

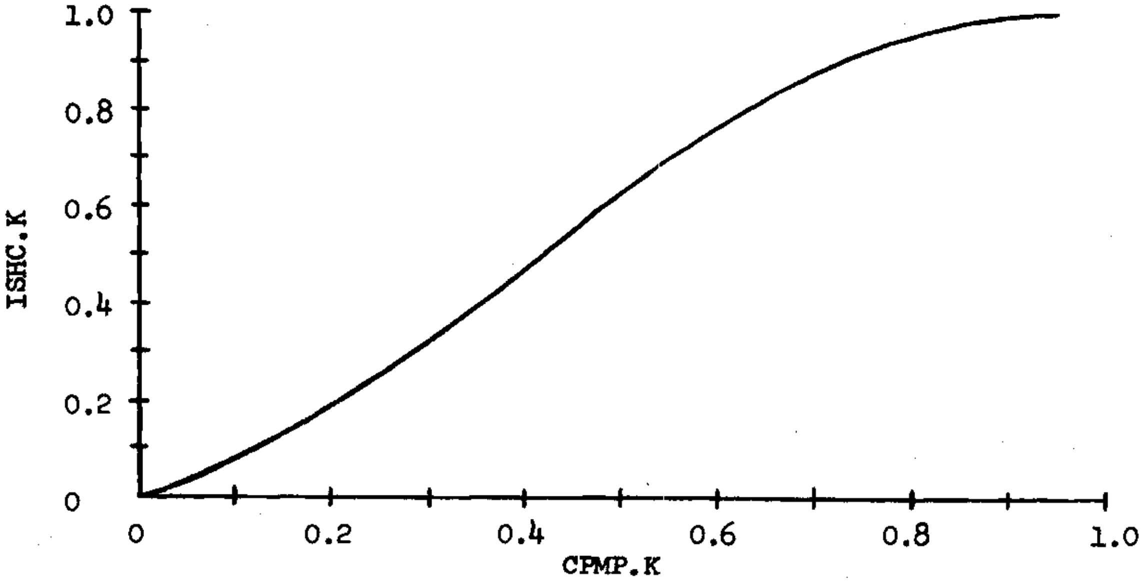

Figure 20. IPMP Versus CPMP.

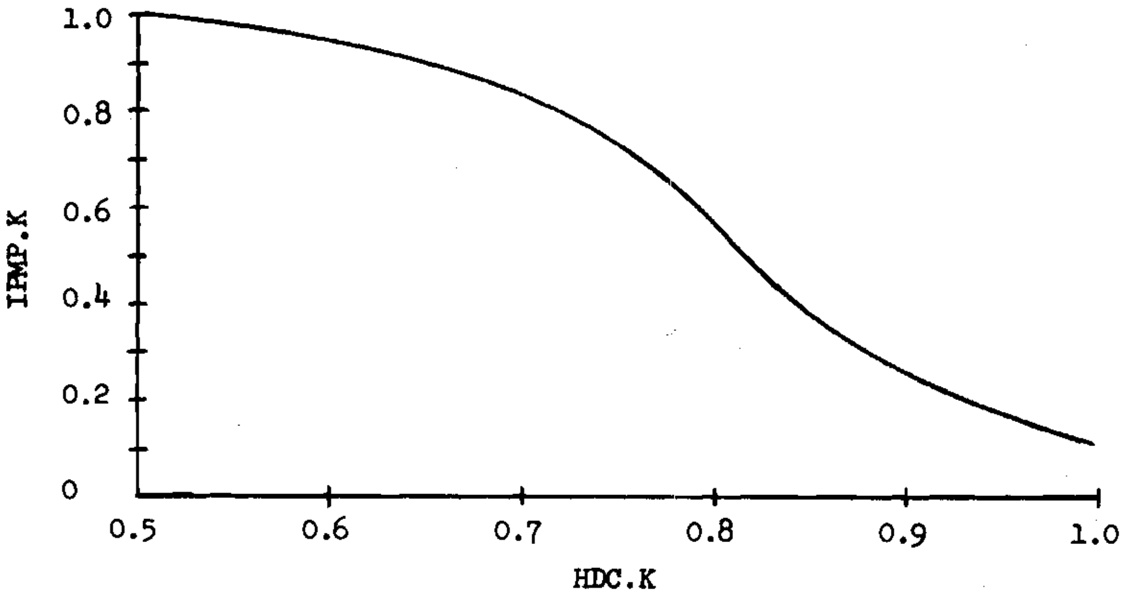

Figure 21. ISHC Versus HDC.

DEF - Development EFfort (man-months)
CDEF - Change in Development EFfort (man-months/month)
PDEF - Planned Development EFfort (man-months/month)
DBDEF - Delay in Beginning Development EFfort (months)
MDEF - Maximum Development EFfort (man-months/month)
IPMP - Impact of Perceived Market Potential (dimensionless)
TIPMP - Table of IPMP versus PMP - Figure 20
CPMP - Colored Perceived Market Potential (dimensionless)
ISHC - Impact of the Saturation of Hardware disposal Capability (dimensionless)
TISHC - Table of ISHC versus HDC - Figure 21
HDC - Hardware Disposal Capability (dimensionless)

The flow diagram for development effort appears in Figure 22.

Hardware Disposal Capability

The capability of the disposal appliance, as explained in the government reactions sector, is measured as a dimensions quantity ranging from zero to one. It depends on the amount of effective development effort which has been devoted to the product and Whirlpool's willingness to implement the results of the development effort.

The effectiveness of the development effort expended in any one month is assumed to be a function of the absolute magnitude of the percentage change in development effort, that is, the effort for that month divided by the cumulative total of effort in past months. Therefore, the effective development effort for the month is calculated as the product of the change in development effort and an effectiveness coefficient. The functional relationship between the effectiveness coefficient and the percentage change in development effort is shown in Figure 24. The maximum effectiveness if assumed to occur in the area of a 30 per cent change. Even at its maximum, the effectiveness coefficient is less than

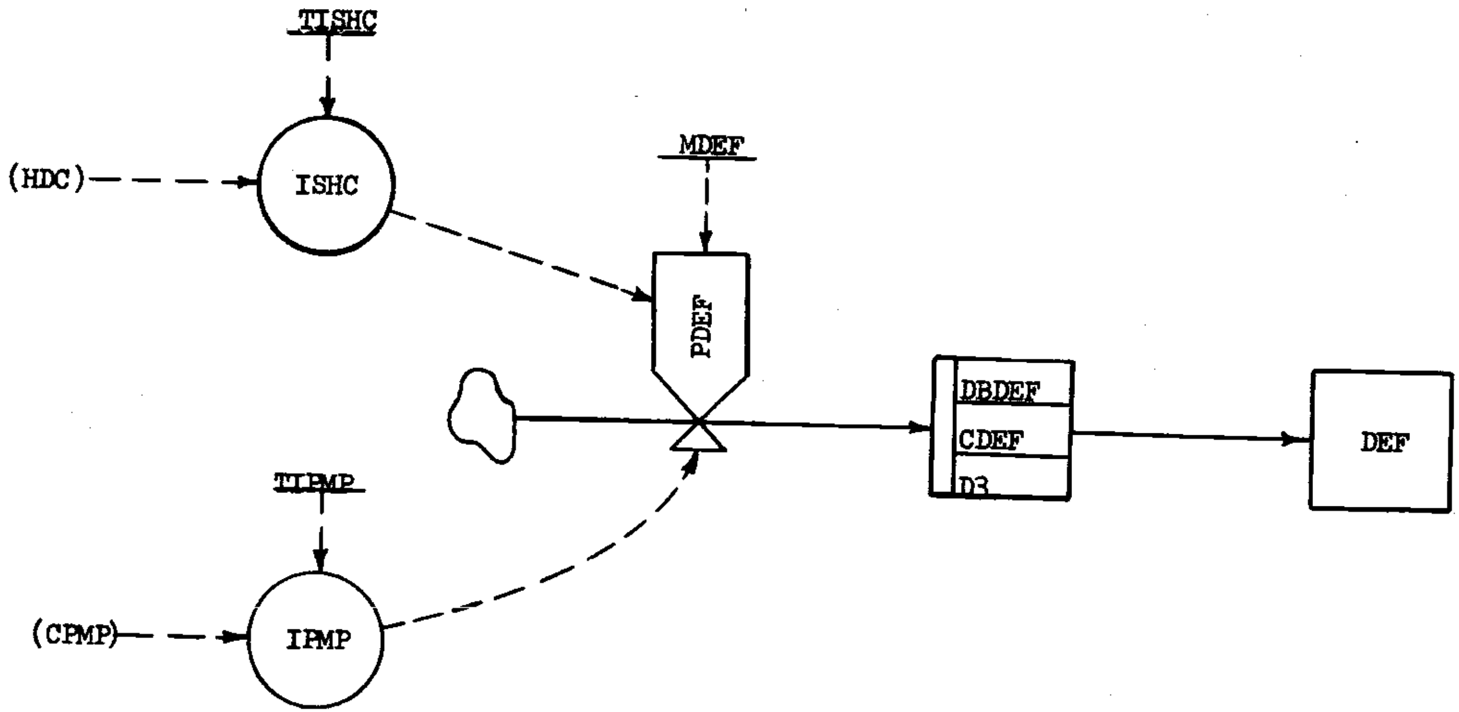

Figure 22. Development Effort.

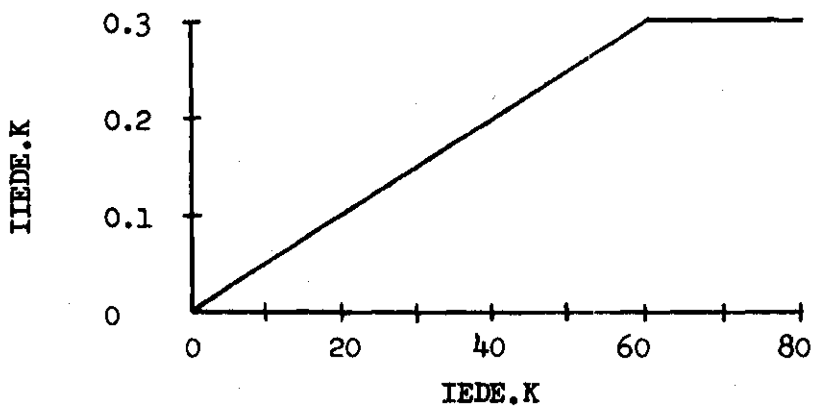

Figure 23. IIEDE Versus IEDE.

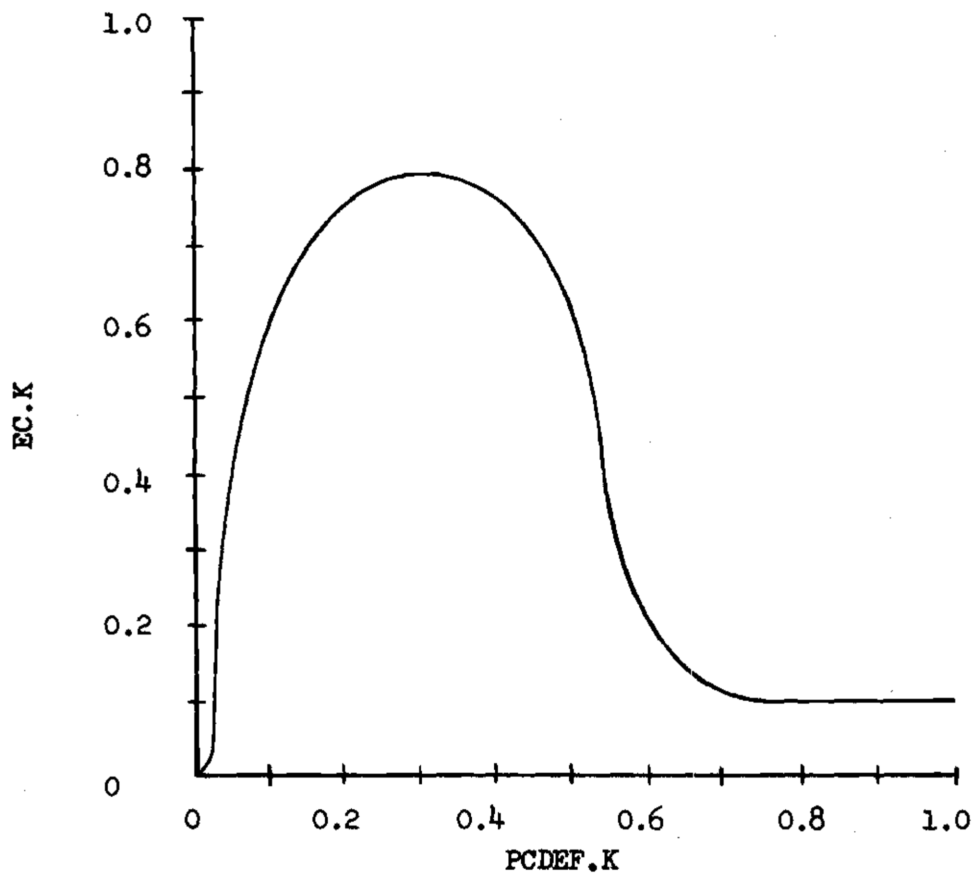

Figure 24. EC.K Versus PCDEF.

one, since some effort will always be ineffective. For small percentage changes, which are likely to occur after the product is fairly well developed, the effectiveness is low, since the effort is probably directed at minor changes. For large percentage changes, which will occur during the initial stages of development, the effectiveness is also low, since many alternative designs will undoubtedly be tried.

The effective development effort is accumulated in a level. The planned implementation of the effective effort depends on the level of effective effort available and the impact of perceived market potential. The impact of perceived market potential was developed in the previous section. After a delay of 12 months to allow for the adaptation of production facilities to the new design changes, the planned implementation of effective development effort becomes an actual implementation. The hardware disposal capability is then increased by a frction of the difference between perfect capability and its present capability. The fraction is an increasing function of the amount of effective effort that is implemented and it is shown in Figure 23.

```
HDC.K=HDC.J+(DT)(CHHDC.JK+0)
CHHDC.KL=(IIEDE.K)(1.0-HDC.K)
IIEDE.K=TABHL(TIIDE,IEDE.JK,0,12,2)
TIIDE*=0/0.05/0.10/0.15/0.20/0.25/0.30
IEDE.KL=DELAY3(PIEDE.JK,DIEDE)
DIEDE=12
PIEDE.KL=(IPMP.K)(LAEDE.K)
LAEDE.K=LAEDE.J+(DT)(EDE.JK-PIEDE.JK)
EDE.KL=(EC.K)(CDEF.JK)
EC.K=TABHL(TEC,PCDEF.K,0,1,0.1)
TEC*=0/0.58/0.76/0.80/0.74/0.38/0.17/0.10/0.10/0.10
PCDEF.K=CDEF.JK/DEF.K
```

HDC - Hardware Disposal Capability (dimensionless)

CHHDC - Change in Hardware Disposal Capability (1/month)
IIEDE - Impact of Implemented Effective Development Effort (dimensionless)
TIIDE - Table of IIEDE versus IEDE - Figure 23
IEDE - Implemented Effective Development Effort (effective man-months/month)
PIEDE - Planned Implementation of Effective Development Effort (effective man-months/month)
DIEDE - Delay in Implementing Effective Development Effort (months)
IPMP - Impact of Perceived Market Potential (dimensionless)
LAEDE - Level of Available Effective Development Effort (effective man-months)
EDE - Effective Development Effort (effective man-months/month)
EC - Effectiveness Coefficient (dimensionless)
TEC - Table of EC versus PCDEF - Figure 24
PCDEF - Percentage Change in Development Effort (dimensionless)
CDEF - Change in Development Effort (man-months/month)
DEF - Development EFfort (man-months)

The hardware disposal capability sector is shown in flow diagram form in Figure 25.

Source Reduction Capability

As explained earlier, source reduction capability is a dimensionless quantity that ranges over the non-negative real numbers. The value zero indicates the elimination of all waste at its point of origin through improved packaging materials and techniques as well as other technological progress. The value one is the index for the present state-of-the-art. Values greater than one indicate a compounding of the problem on the part of the source industries.

It should be help in mind that an increase in source reduction capability, of the source industries, is actually represented as a rate which drives the numerical magnitude of source reduction capability toward zero. Conversely, a decrease in source reduction capability will

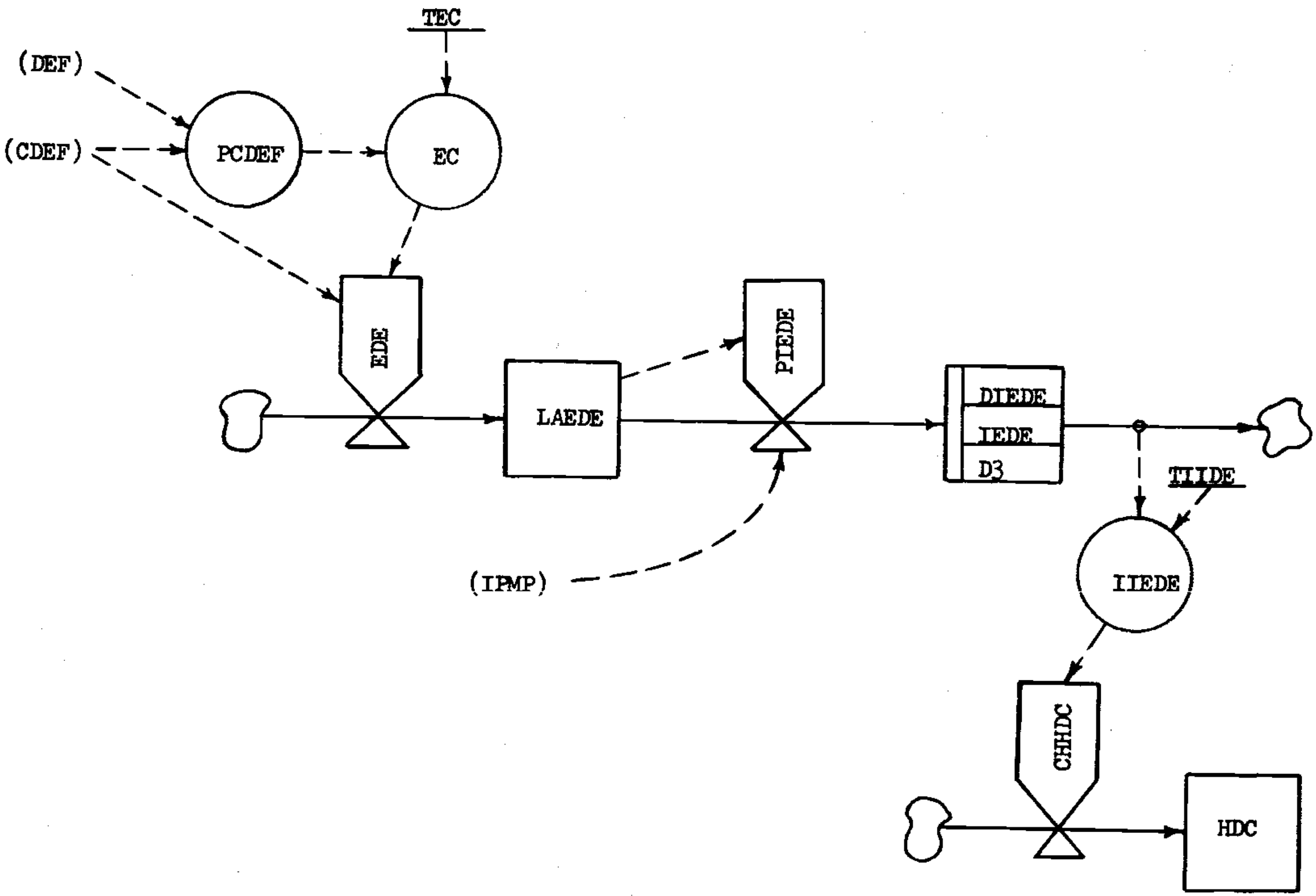

Figure 25. Hardware Disposal Capability.

actually increase the numerical magnitude of the variable.

SRC.K=SRC.J+(DT)(-ISRC.JK+DSRC.JK)

SRC - Source Reduction Capability (dimensionless)
ISRC - Increase in Source Reduction Capability (1/month)
DSRC - Decrease in Source Reduction Capability (1/month)

An increase in source reduction capability may be voluntarily planned by the source industries or it may be required by government action. The actual increase in any one month would be the maximum of these two types of increase for that particular month.

KSRC.KL=MAX(ISRCL.JK,ISRCG.JK)

ISRCI - Increase in Source Reduction Capability due to Industry (1/month)
ISRCG - Increase in Source Reduction Capability due to the Government (1/month)

The increase in source reduction capability is planned on the basis of the present capability and the impacts of hardware disposal capability and daily disposal needs. The impact of hardware disposal capability is negatively sloped as shown in Figure 26, since an increase in hardware disposal capability represents an alternative solution to the waste disposal problem. The impact of daily disposal needs represents pressure from the environment to alleviate the problem. It is shown in Figure 27 and is positively sloped as would be expected. The product of these two impacts, divided by a normalizing factor of ten, gives the fraction by which the numerical magnitude of source reduction capability is to be reduced. This planned increase in capability is to

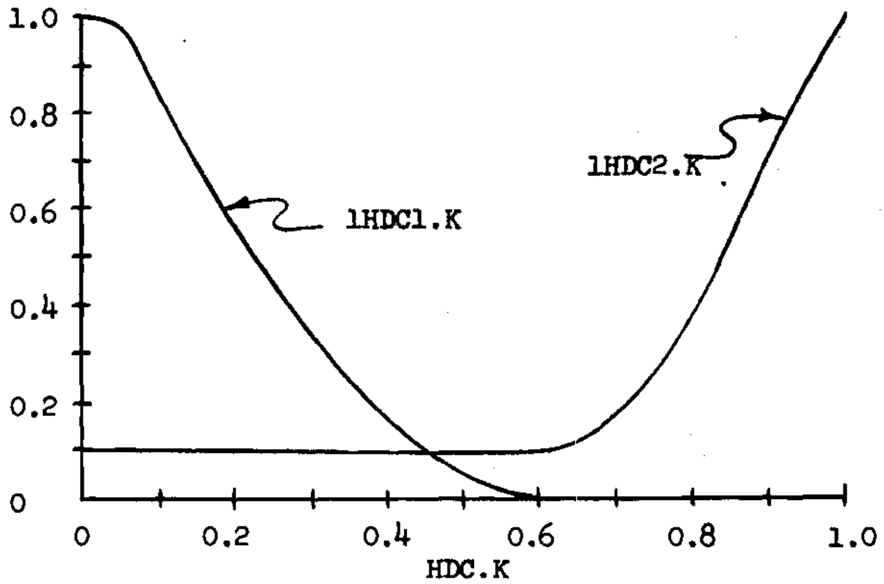

Figure 26. IHDC1 and IHDC2 Versus HDC.

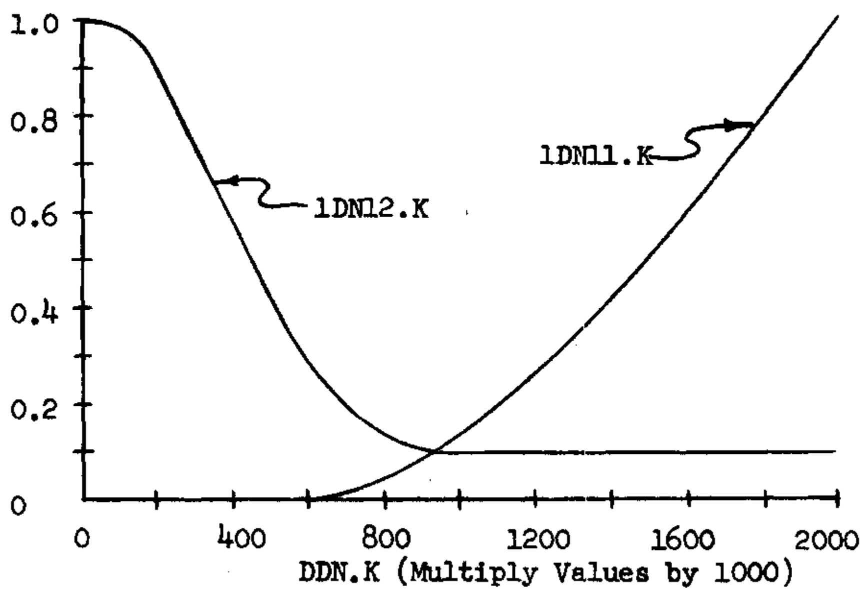

Figure 27. IDNLL and IDNI2 Versus DDN.

be reduced. This planned increase in capability, after an average delay of 60 months or five years, becomes the actual increase. Note again that the decrease in numeric magnitude of the variable indicates an increase in capability. The delay in bringing about the increase in capability is rather large due to the need to develop the materials or techniques needed, the adaptation of production facilities by the source industries, and the need to sell the planned changes to the customers.

```
ISRCI.KL=DELAY3(PISRC.JK,DISRC)
DISRC=60
PISRC.KL=(SRC.K)(LHDCL.K)(IDNII.K)/((10)(I)(L))
IHDCI.K=TABHL(TIHCI.HDC.K,0,0.6.0.1)
TIHCI*=1.0/0.80/0.54/0.33/0.15/0.04/0
IDNI1.K=TABHL(TIDN.1,DDN.K,600000,2000000,200000)
TIDNI*=0/0.04/0.13/0.25/0.41/0.60/0.82/1.0
```

PISRC - Planned Increase in Source Reduction Capability (1/month)
DISRC - Delay in Increasing Source Reduction Capability (months)
IHDC1 - Impact of Hardware Disposal Capability #2 (dimensionless)
TIHC1 - Table of IHDC1 versus HDC - Figure 26
HDC - Hardware Disposal Capability (dimensionless)
IDNI1 - Impact of daily Disposal Needs on Industry #1 (dimensionless)
TIDN1 - Table of IDNI1 versus DDN - Figure 27
DDN - Daily Disposal Needs (thousands of pounds/day)

The increase in capability due to the government is a reduction in numerical magnitude equal to the product of the present capability and a government imposed reduction factor. The imposed reduction factor is an increasing function of government alarm over the waste problem, a variable which was defined in the government reactions sector. The relationship is shown in Figure 28. There is no delay in bringing about

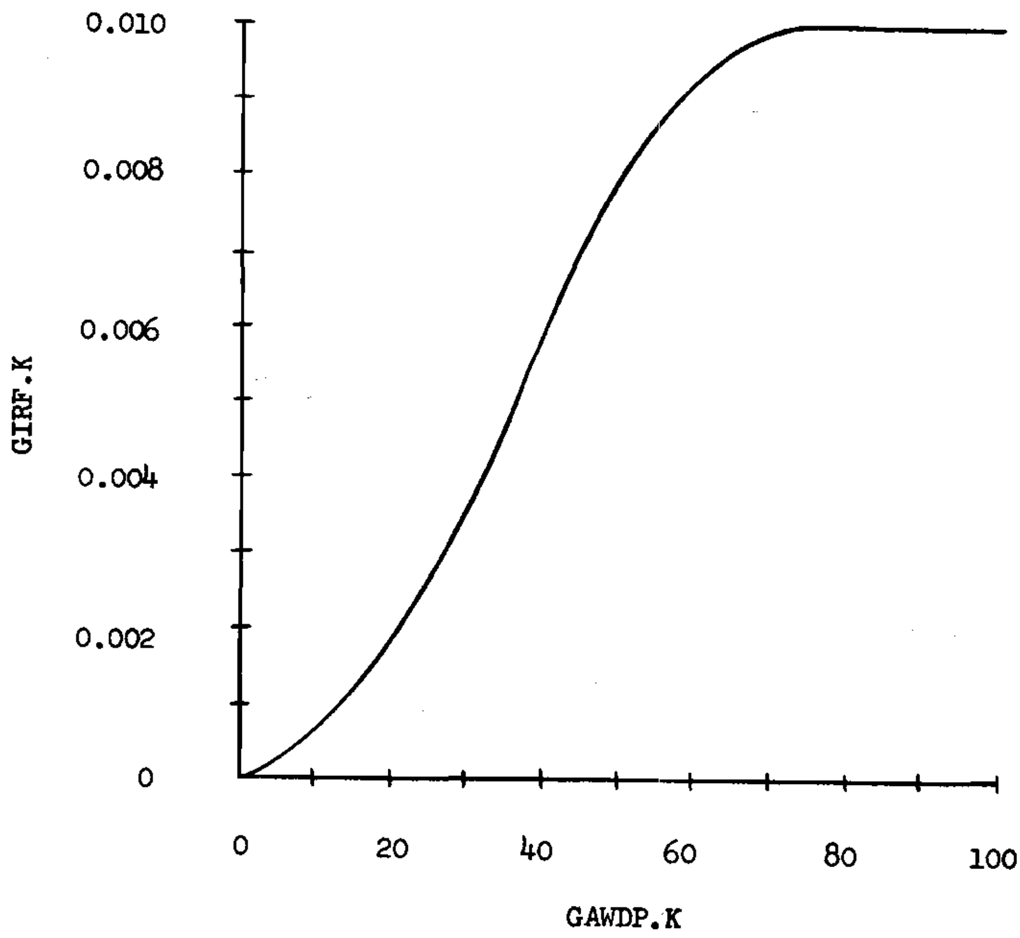

Figure 28. GIRF Versus GAWDP.

this increase in capability, since the government action is assumed to be only a requirement that previously developed waste saving techniques to put into use. In addition, there is no need to seel the change to the customer, if the change is required by law.

```
ISRCG.KL=(SRC.K)(GIRF.K)
GIRF.K=TABLE(TGIRF,GAWDP.K,0,100,10)
TGIRF*=0/.0005/.0017/0035/.0060/.0083/.0095/.01/.01/.01/.01
```

GIRF - Government Imposed Reduction Factor (dimensionless)
TGIRF - Table of GIRF versus GAWDP - Figure 28
GAWDP - Government Alarm over the Waste Disposal Problem (dimensionless)

The formulation for decreases in source reduction capability is much the same as that for increases in capability due to the source industries. The impacts of hardware disposal capability and daily disposal needs are shown in Figures 26 and 27 respectively. As expected, these curves slope oppositely from the corresponding impact functions dealing with increasing capability. Notice that neither curve ever reaches zero. This indicates that there is always pressure from customers to decrease source reduction capability in order to satisfy other demands, such as the marketing value of packaging. The delay in converting planned decreases in capability to actual decreases is 36 months or three years. It is shorter than the delay to bring about increases in capability, since these changes are brought about by customer demands, and there is no need to sell the change to the customer.

```
DSRC.KL=DELAY3(PDSRC.JK,DDSRC)
```

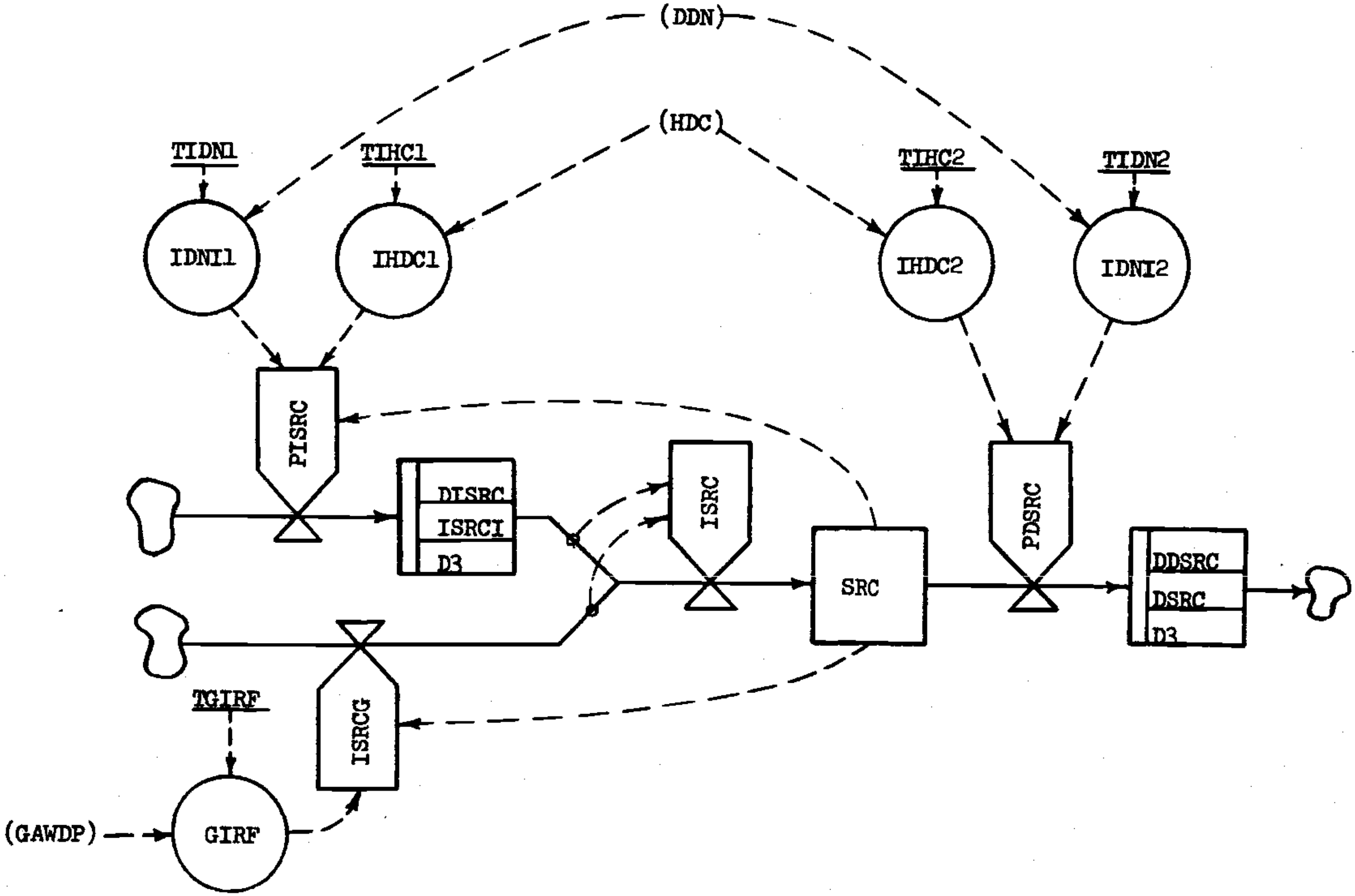

Figure 29. Source Reduction Capability.

```
DDSRC=36
PDSRC.KL=(IHDC2.K)(IDNI2.K)/10
IHDC2.K=TABHL(TIHC2,HDC.K,0.6,1,0.1)
TIHC2*=0.10/0.10/0.43/0.73/0
IDNI2.K=TABHL(TIDN2,DDN.K,0,900000,100000)
TIDN2*=1.0/0.97/0.89/0.77/0.62/0.44/0.28/0.18/0.13/0.10
```

PDSRC - Planned Decrease in Source Reduction Capability (1/month)
DDSRC - Delay in Decreasing Source Reduction Capability (months)
IHDC2 - Impact of Hardware Disposal Capability #2 (dimensionless)
TIHC2 - Table of IHDC2 versus HDC - Figure 26
IDNI2 - Impact of Disposal Needs on Industry #2 (dimensionless)
TIDN2 - Table of IDNI2 versus DDN - Figure 27

The flow diagram for this sector is shown in Figure 29.

Sales Effort

Sales effort is measured in dollars spent per month and is planned in much the same way as development effort. The maximum sales effort devoted to the disposal appliance for any one month is taken as 100,000 dollars. The same argument with regard to accuracy applies to this assumption as in the case of the maximum development effort of five man-months per month. The product of this maximum sales effort and the impacts of perceived market potential and hardware disposal capability determine the planned sales effort for the month. The impact of perceived market potential is the same function that was illustrated in the development effort sector of the model. The impact of hardware disposal capability, Figure 30, is an increasing function of hardware capability, since sales effort would naturally tend to increase as the product becomes more salable.

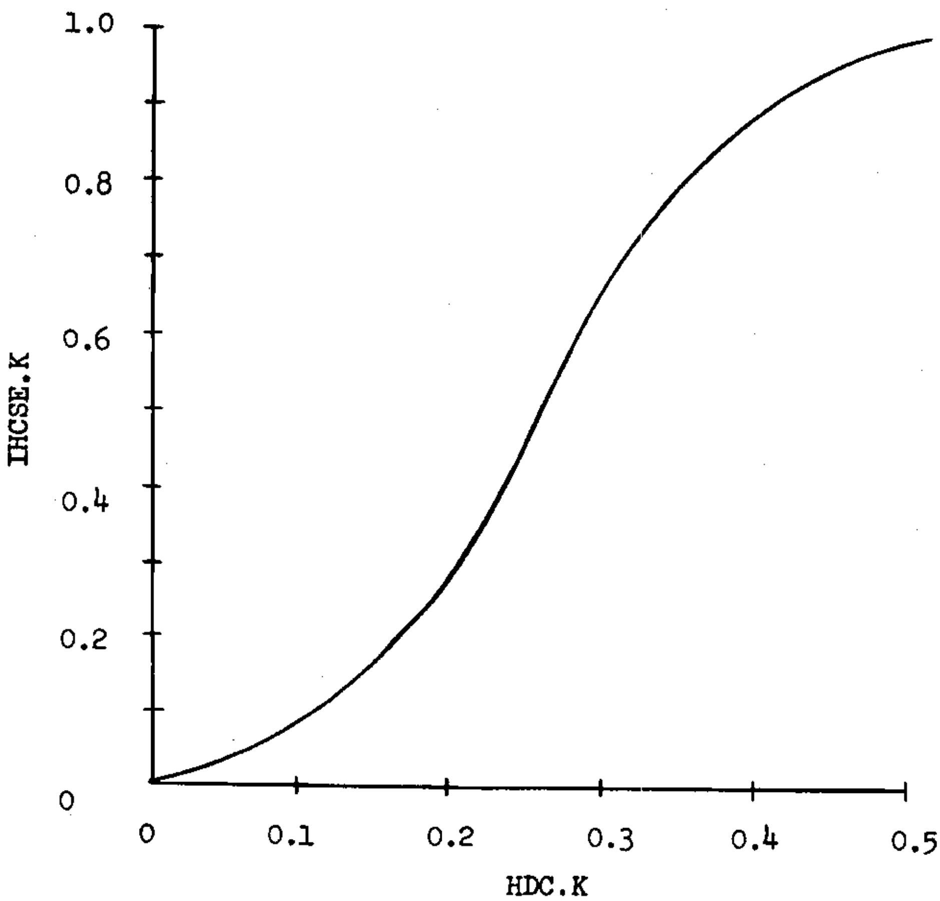

Figure 30. IHCSE Versus HDC.

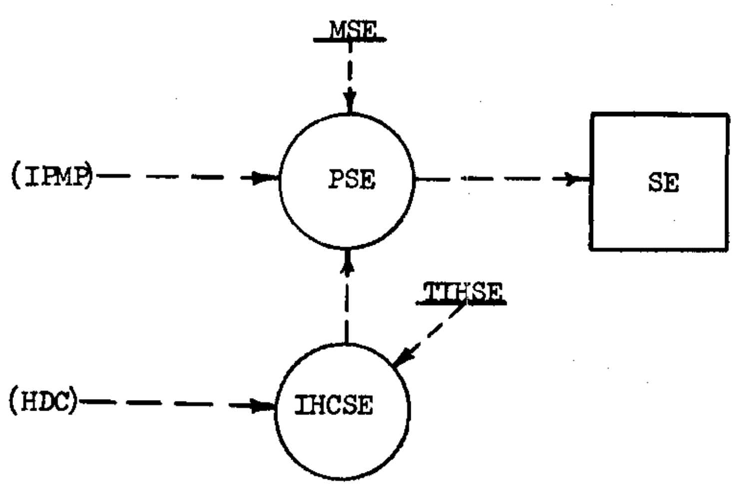

Figure 31. Sales Effort.

The actual sales effort is a first order delay of planned sales effort with an average delay of six months. The reason for using a first order rather than a third order delay in this case is that when a decision is made to change sales effort, some portion of that decision could be activated almost immediately simply by notifying the sales force of the decision.

```
SE.K=SE.J+(DT)(1/6)(PSE.J-SE.J)
PSE.K=(MSE)(IPMP.K)(IHCSE.K)
MSE=100000
IHCSE.K=TABHL(TIHSE,HDC.K,0,0.5,0.1)
TIHSE*=0/0.6/0.27/0.72/0.84/1
```

```
SE    - Sales Effort (dollars/month)
PSE   - Planned Sales Effort (dollars/month)
MSE   - Maximum Sales Effort (dollars/month)
IPMP  - Impact of Perceived Market Potential (dimensionless)
IHCSE - Impact of Hardware Capability on Sales Effort
        (dimensionless)
TIHSE - Table of IHCSE versus HDC - Figure 30
HDC   - Hardware Disposal Capability (dimensionless)
```

The flow diagram for the sale effort sector is shown in Figure 31.

Sales and Implementation

The sales made in any one month are determined by the market size during that month and three factors that affect sales. The three factors are the effect of family daily disposal needs, the effect of sale effort, and the effect of hardware disposal capability. These effects are all positively sloped for obvious reasons, and they are shown in Figures 32 through 34 respectively. The number of sales for the month in thousands is computed as the market size times the product of the three

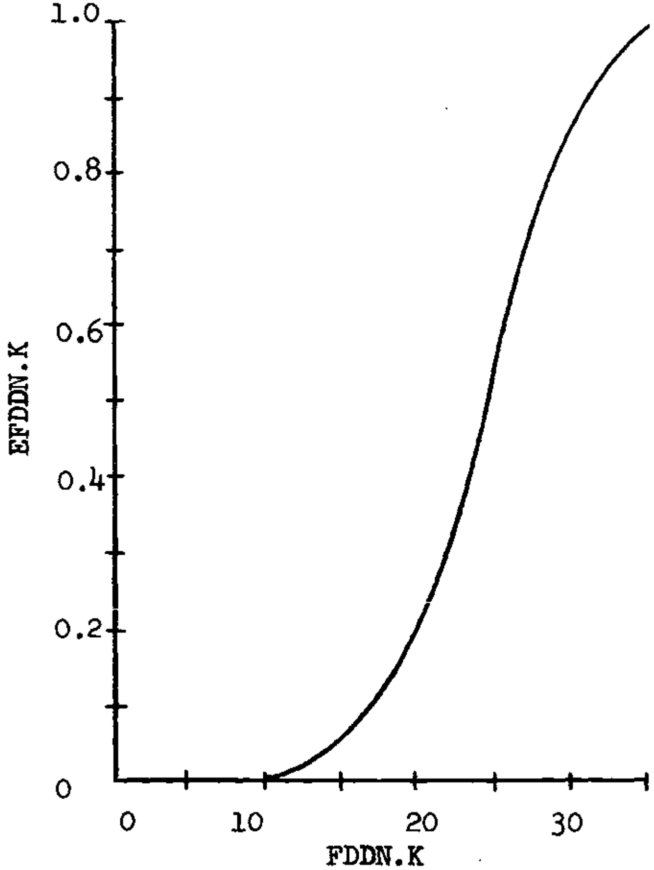

Figure 32. EFDDN Versus FDDN.

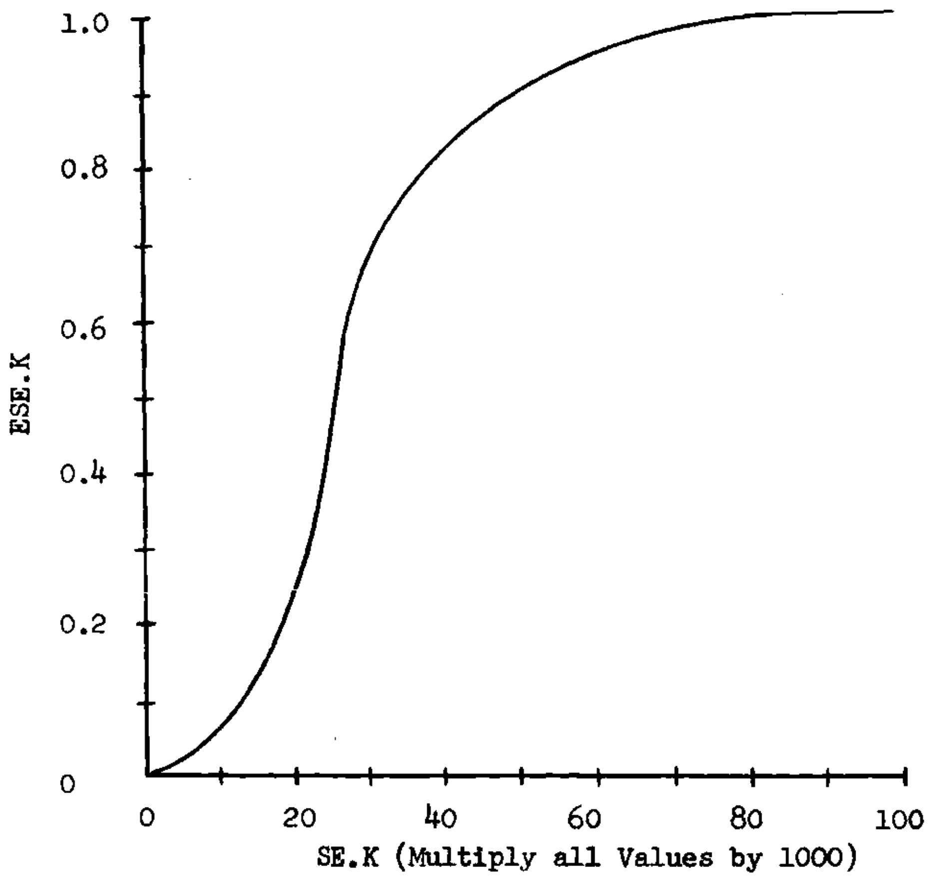

Figure 33. ESE Versus SE.

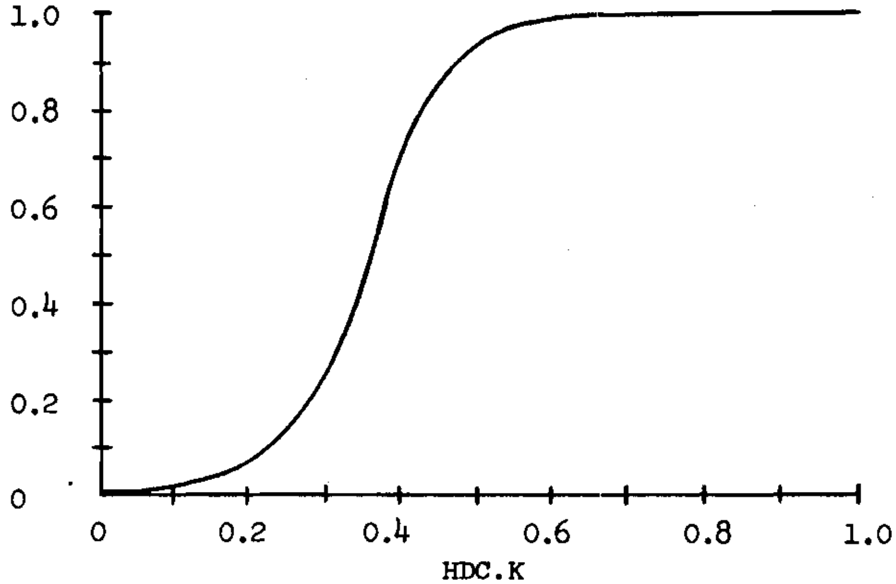

Figure 34. EHDC Versus HDC.

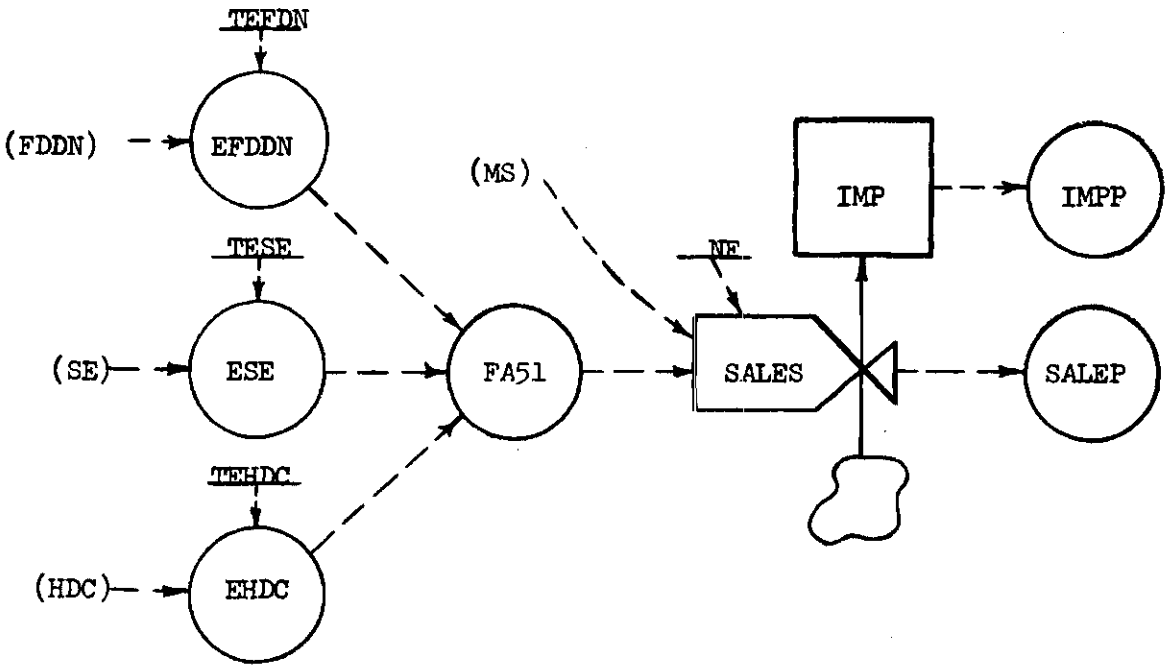

Figure 35. Sales and Implementation.

factors affecting sales divided by a normalizing factor. Another variable, referred to as implementation, is used to keep a cumulative total of the sales in thousands to date. Supplementary variables are used to convert the values of monthly sales and total implementation from expressions in terms of thousands to absolute magnitudes for plotting purposes.

```
IMP.K=IMP.J+(DT)(SALES.JK+0)
SALES.KL=(MS.K)(FASI.K)/NF
NF=3000
FASI.K=(EFDDN.K)(ESE.K)(EHDC.K)
EFDDN.K=TABHL(TEFDN,FDDN.K,0,35,5)
TEFDN*=0/0/0/0.06/0.22/0.52/0.89/1.0
ESE.K=TABLE(TESE,SE.K,0,100000,10000)
TESE*=0/0.04/0.23/0.71/0.84/0.91/0.95/0.98/0.99/1.0/1.0
EHDC.K=TABLE(TEHDC,HDC.K,0,1,0.1)
TEHOC*=0/0.02/0.07/0.21/0.65/0.95/1.0/1.0/1.0/1.0/1.0
SALEP.K=(1000)(SALES.JK)
IMPP.K=(1000)(IMP.K)
```

```
IMP    - IMPlementation (thousands of units sold)
SALES  - SALES (thousands of units sold/month)
MS     - Market Size (thousands of families)
FASI   - Factors Affecting Sales (dimensionless)
NF     - Normalizing Factor (dimensionless)
EFDDN  - Effect of Family Daily Disposal Needs (dimensionless)
TEFDN  - Table of EFDDN versus FDDN - Figure 32
FDDN   - Family Daily Disposal Needs (pounds/family/day)
ESE    - Effect of Sales Effort (dimensionless)
TESE   - Table of ESE versus SE - Figure 33
SE     - Sales Effort (dollars/month)
EHDC   - Effect of Hardware Disposal Capability (dimensionless)
TEHDC  - Table of EHDC versus HDC - Figure 34
HDC    - Hardware Disposal Capability (dimensionless)
SALEP  - SALEs for Plotting (units sold/month)
IMPP   - IMPlementation for Plotting (units sold)
```

The flow diagram for this sector appears in Figure 35.

Public Acceptance

Public acceptance is assumed to be an increasing dimensionless function of the total number od disposal appliances that have been sold to date. This assumes that as the product becomes a more common household item, there will be less resistance to purchase such a device on the part of those people who do not yet own one. The relationship is shown in Figure 36.

```
PA.K=TABHL(TPA,IMP.K,0,22050,1470)
TPA*=0/0.01/0.04/0.09/0.16/0.24/0.33/0.43/0.53/0.63/0.73/
     0.81/0.88/0.93/0.95/0.95
```

PA - Public Acceptance (dimensionless)
TPA - Table of PA versus IMP - Figure 36
IMP - IMPlementation (thousands of units sold)

Due to the simplicity of this sector, no flow diagram is shown.

Initial Conditions

The initial conditions were assigned such that the model at time zero represents the present situation in the real world system, that is, the situation at the time this research was done.

POP=200000

POPGR=0

CF=58824

PFGR=0

RBP=0

MS=0

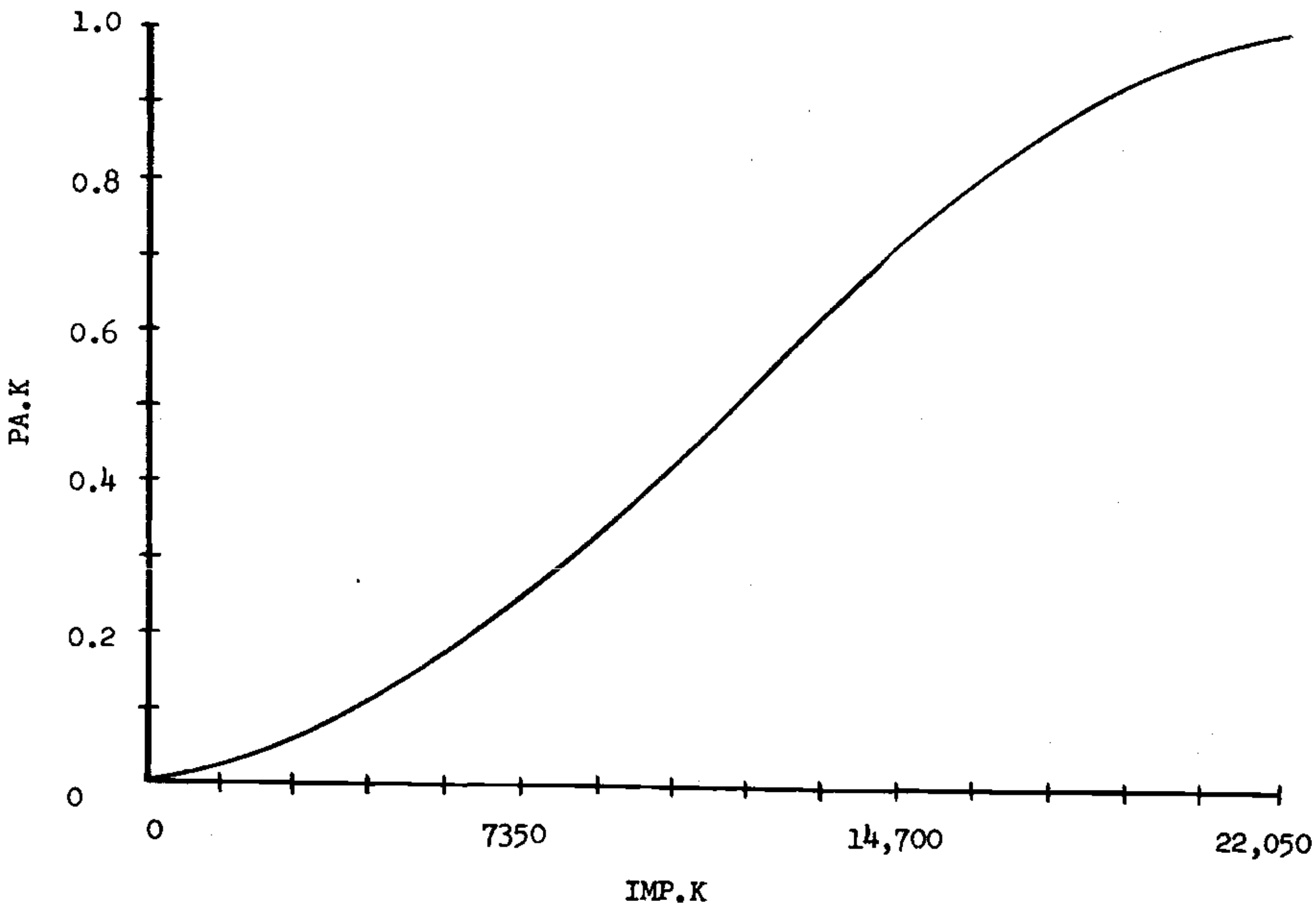

Figure 36. PA.K Versus IMP.K

SSRC=1.0

PGMGA=0

PMP=0

DEF=0.001

PDEF=0

HDC=0

PIEDE=0

LAEDE=0

SRC=1.0

PISRC=0

PDSRC=0

SE=0

IMP=0

SALES=0

Model Validation

There are two essential requirements which must be met if a model is to be judged as valid. First, the structure of the model must be a realistic representation of the real world system. The structure of the model and the reasoning supporting it have already been presented for judgment.

The second requirement is that the model must show behavior which is considered reasonable for the real world system. Since the expected behavior of the real world system is a matter of conjecture, the model was tested in sections. The sections were chosen so that the behavior which would seem reasonable for each section is known. The sections that were tested, along with the actual simulation runs, are shown in Appendix C. In each case, the section of the model which was being tested was made insensitive to the rest of the model. All outside effects on that section were supplied as constants, and the behavior of that section only was studied. Two simulation runs were made on each section. The first run was made under conditions very close to the initial conditions of the model. The second run was made under conditions representing a greater magnitude of the waste disposal problem. In each case, the section of the model that was under study behaved in the manner that would be expected of the real world system under similar conditions.

Therefore, the explanation of the model structure and the test simulation runs in Appendix C are presented as the necessary evidence to support the validity of the model.

Model Sensitivity

In the Procedure, it was stated that when model parameters were set by estimation due to lack of better information, the model would be tested for sensitivity to those parameters. A large number of such tests were made by making several runs while varying one parameter over its feasible range. The only effects that were observed in model behavior were slight changes in the timing of model reactions and in the magnitudes of some variables. In no case, however, was the mode of dynamic behavior affected. That is to say that although the pattern of behavior was shifted slightly on the time scale and although the behavior was amplified or attenuated slightly, the basic pattern of behavior was the same in all cases. Since it is this pattern of behavior which is of primary interest in this research, the parameters were accepted as they had been set.

The actual simulation runs that comprised these tests are not shown due to their excessive bulk, their similarity, and their lack of illustrative value.

CHAPTER V

RESULTS

The results of the model experiments will be presented as a comparison of three separate simulation runs.

Run #1

The first simulation run was made with the model set up exactly as described in the previous chapter. The model behavior for 30 years of simulated time is shown in Figures 37 and 38.

First, as a general overview, the shape of the curve representing monthly sales should be noted. It is almost ten years before the curve begins to rise. The curve rises at an increasing rate until the twenty-first year (252 months), when its rate of ascent begins to decrease. By the thirtieth year, the sales curve has almost completely leveled off. It is interesting to note that this is the same sales pattern which has been experienced by the manufacturers of conventional garbage disposal units.

As would be expected, the magnitude of the disposal problem on the family level, as well as the national level, begins to grow from time zero. Accordingly, the market for the disposal device begins to grow. Whirlpool, perceiving this market, begins to allocate manpower to the development effort for the product. In the fourth year, the government's alarm over the problem begins to grow, resulting in a forced improvement in source reduction capability. The public perceives this improvement

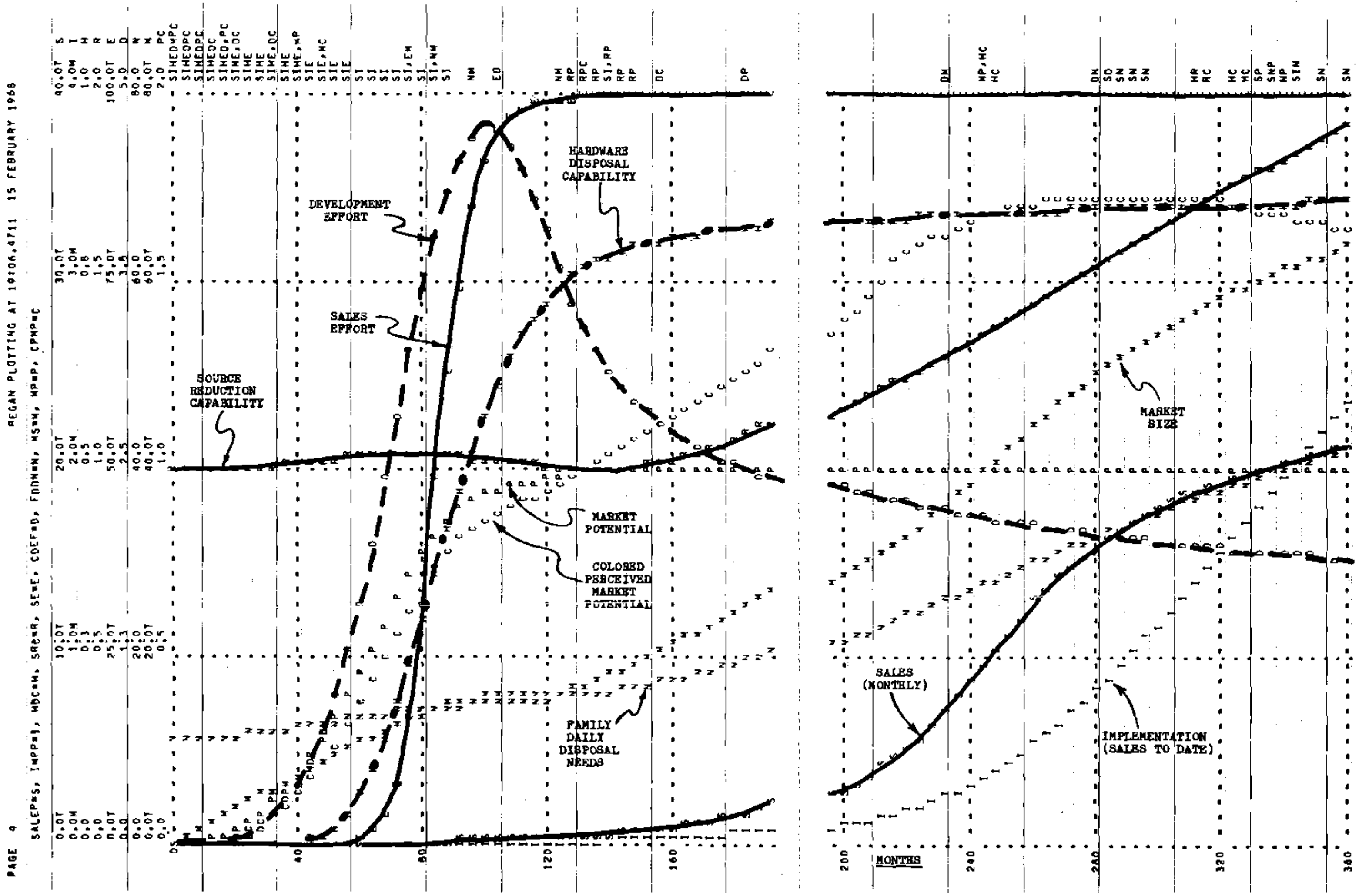

Figure 37. Run #1 - Plot #1.

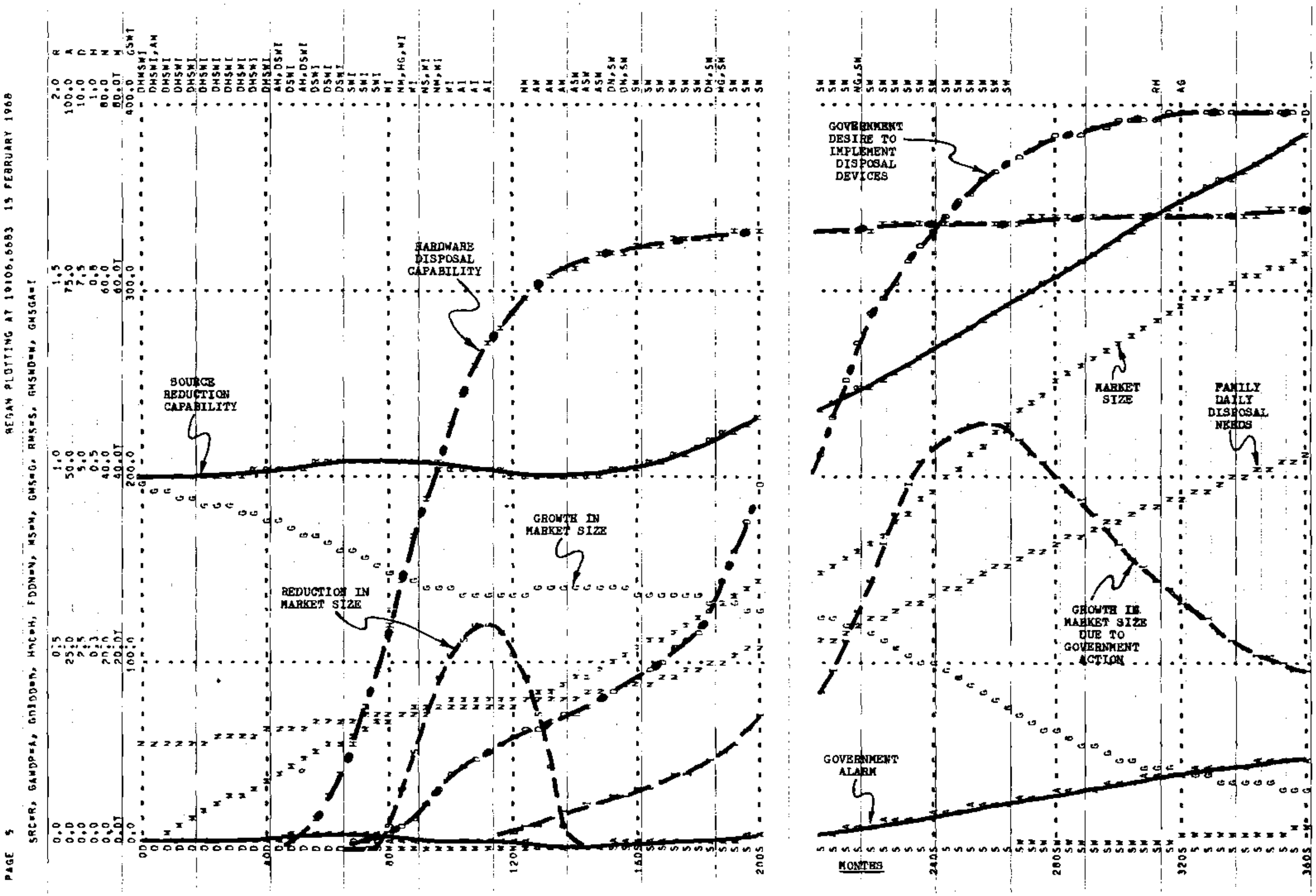

Figure 38. Run #1 - Plot #2.

and for a period of about five years, families are leaving the market almost as fast as they are entering it. Eventually, the increasing hardware capability of the disposal device relieves the government's alarm over the problem. The pressure on the source industries is reduced, and the magnitude of the problem begins to grow again, bringing subsequent growth in the market. In addition, the government's desire to implement the disposal device increases as the device becomes more fully developed. This reaction causes a growth in market size due to government action, which begins in the tenth year and continues through the end of the simulation run.

The behavior in run #1 may be briefly summarized as follows:

(1) The sales rate was slow in rising, and it leveled off rather quickly.

(2) There was a period of danger from the fifth to the tenth year, when the government's alarm over the problem and the subsequent pressure to improve source reduction capability threatened to destroy the market for the disposal device.

(3) It was the government's reaction to the increasing hardware disposal capability, which relieved the pressure on the source industries and allowed the market for the disposal device to grow. Furthermore, this reaction contributed significantly to the growth in the market due to government action.

Run #2

In run #2, the model has been altered slightly to examine system behavior if the government were entirely indifferent to the hardware capability of the disposal device. This would be analogous to a situation in which Whirlpool might develop a product which would be considered by the government as inadequate to meet the disposal needs of the public or unsatisfactory in that it compounds other environmental problems. The hardware capability neither contributes to the relief of government alarm over the problem nor stimulates any desire on the part of the government to implement the disposal appliance.

IGAHC=1.0
IGDHC=0

IGAHC - Impact on Government Alarm of Hardware disposal Capability (dimensionless)
IGDHC - Impact on Government Desire of Hardware disposal Capability (dimensionless)

The remainder of the model is exactly the same as in run #1. The resulting behavior is shown in Figures 39 and 40.

The same pattern for monthly sales is produced as in run #1, although the sales rate levels off at a value that is only 55 per cent of the value at which sales leveled off in run #1. Furthermore, the total implementation is only 61 per cent of the implementation achieved in run #1.

There are several important differences between the dynamics of run #2 and run #1. As in run #1, the government begins to become alarmed over the problem in the fourth year. The same effects on source reduction capability and market size are observed as were observed in run #1. In this case, however, the increasing hardware capability does not relieve

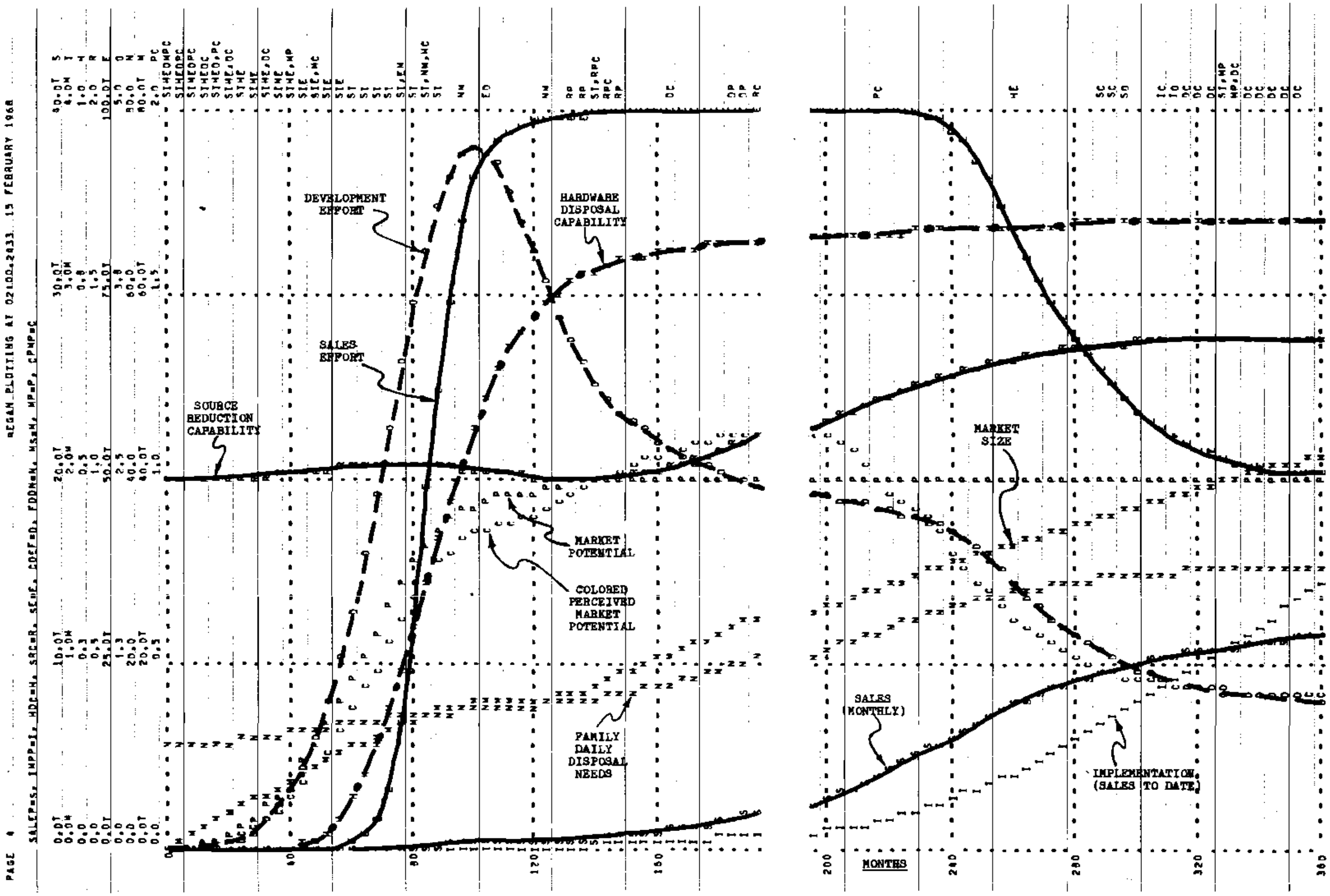

Figure 39. Run #2 - Plot #1.

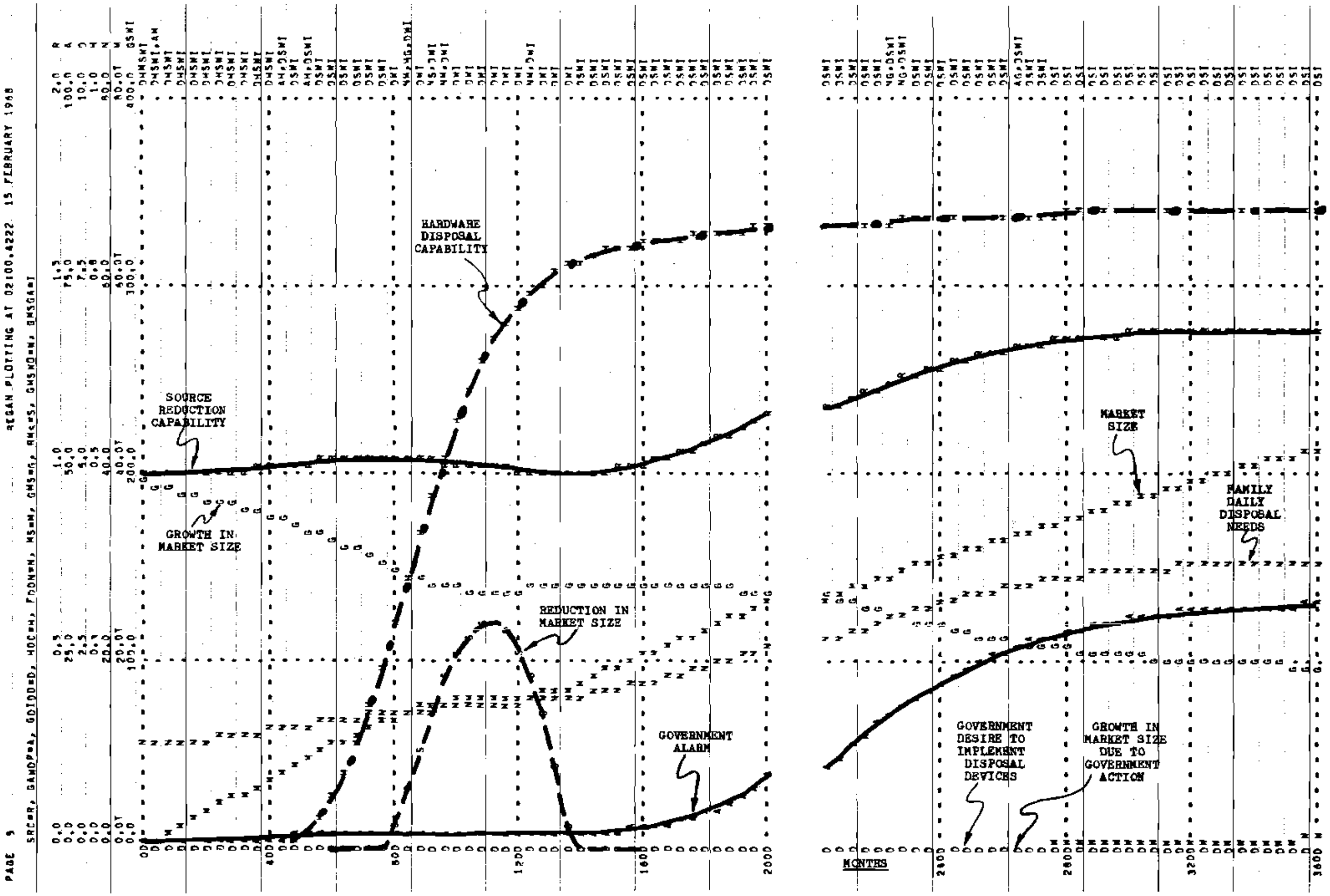

Figure 40. Run #2 - Plot #2.

government alarm, nor does it cause a desire on the part of the government to implement disposal devices. Government alarm does not subside, and in fact, it continues to increase. Source reduction capability continues to deteriorates at a much slower rate than in run #1, and eventually levels off at a value that is only 74 per cent of the level reached in run #1. The increasing government alarm and the subsequent control of the waste disposal problem causes Whirlpool to perceive a reduced market potential, which after 20 years, results in a decrease in sales effort.

In effect, the government has taken the initiative away from Whirlpool in run #2, and by controlling the waste problem at its source, has rendered the disposal appliance relatively unsalable. The dangers of this situation are more grave than this simulation can illustrate. In a situation of this type, the indifference of the government toward the product could develop into a rejection of the product as undesirable for public use. The consequences of such a reaction could be felt throughout the company.

Run #3

In run #3, a new strategy with regard to the allocation of development effort and sales effort is tested. Management's perception of the government's desire to implement the disposal device controls the value of the impact of perceived market potential.

As it relates to the allocation and implementation of development effort, the effective impact of perceived market potential is held constant at its maximum value, 1.0, until the government's desire to implement disposal devices reaches 75 per cent of its maximum value. In other words, Whirlpool commits itself at the outset to develop the capability of the product until the government reacts favorably to the capability. This will be done regardless of the perceived market for the product. As soon as the government reacts favorably to the product, the impact of perceived market potential will begin to function as it normally would to control the further development of the product.

```
PDEF.KL=(MDEF)(EIPPD.K)(ISHC.K)
EIPPD.K=CLIP(IPMP.K,1,GDIDD.K,7.5)
```

PDEF - Planned Development EFfort (man-months/month)
MDEF - Maximum Development EFfort (man-months/month)
EIPPD - Effective Impact of Perceived market Potential on planned Development effort (dimensionless)
ISHC - Impact of Saturation of Hardware Capability (dimensionless)
IPMP - Impact of Perceived Market Potential (dimensionless)
GDIDD - Government Desire to Implement Disposal Devices (dimensionless)

```
PIEDE.KL=(EIPPI.K)(LAEDE.K)
EIPPI.K=CLIP(IPMP.K,1.0,GDIDD.K,7.5)
```

PIEDE - Planned Implementation of Effective Development Effort (effective man-months/month)
EIPPI - Effective Impact of Perceived market Potential on planned Implementation of effective development effort (dimensionless)
LAEDE - Level of Available Effective Development Effort (effective man-months)

As the new strategy relates to sales effort, the effective impact of perceived market potential is held constant at zero until the government's desire to implement the device reaches 75 per cent of its maximum.

At that point, the impact of perceived market potential assumes its normal role in controlling sales effort. This strategy, in effect, prohibits Whirlpool from trying to market its product until the government has shown a favorable reaction to the capability of the product.

```
PSE.K=(MSE)(EIPPS.K)(IHCSE.K)
EIPPS.K=CLIP(IPMP.K,0,GDIDD.K,7.5)
```

PSE - Planned Sales Effort (dollars/month)
MSE - Maximum Sales Effort (dollars/month)
EIPPS - Effective Impact of Perceived market Potential on planned Sales effort (dimensionless)
IHCSE - Impact of Hardware disposal Capability on Sales Effort (dimensionless)

The results of this run are shown in Figures 41 and 42.

Notice that the curve representing the monthly sales rate begins to rise at approximately the same point in time and levels off at the same value as in run #1, but the curve has a different shape from the shape which appeared in run #1. It rises much more steeply in the beginning and is concave downward, resulting in a total implementation that is 48 per cent greater than the implementation achieved in run #1.

Development effort begins immediately, and hardware disposal capability reaches a value of 0.8 approximately six years earlier than in run #1. As a result, government alarm over the problem is suppressed until a later stage in the run. Consequently, source reduction capability deteriorates with little or no restriction from the government. The danger period, which was experienced between the fifth and tenth year in run #1, does not appear in run #3. The government's desire to implement

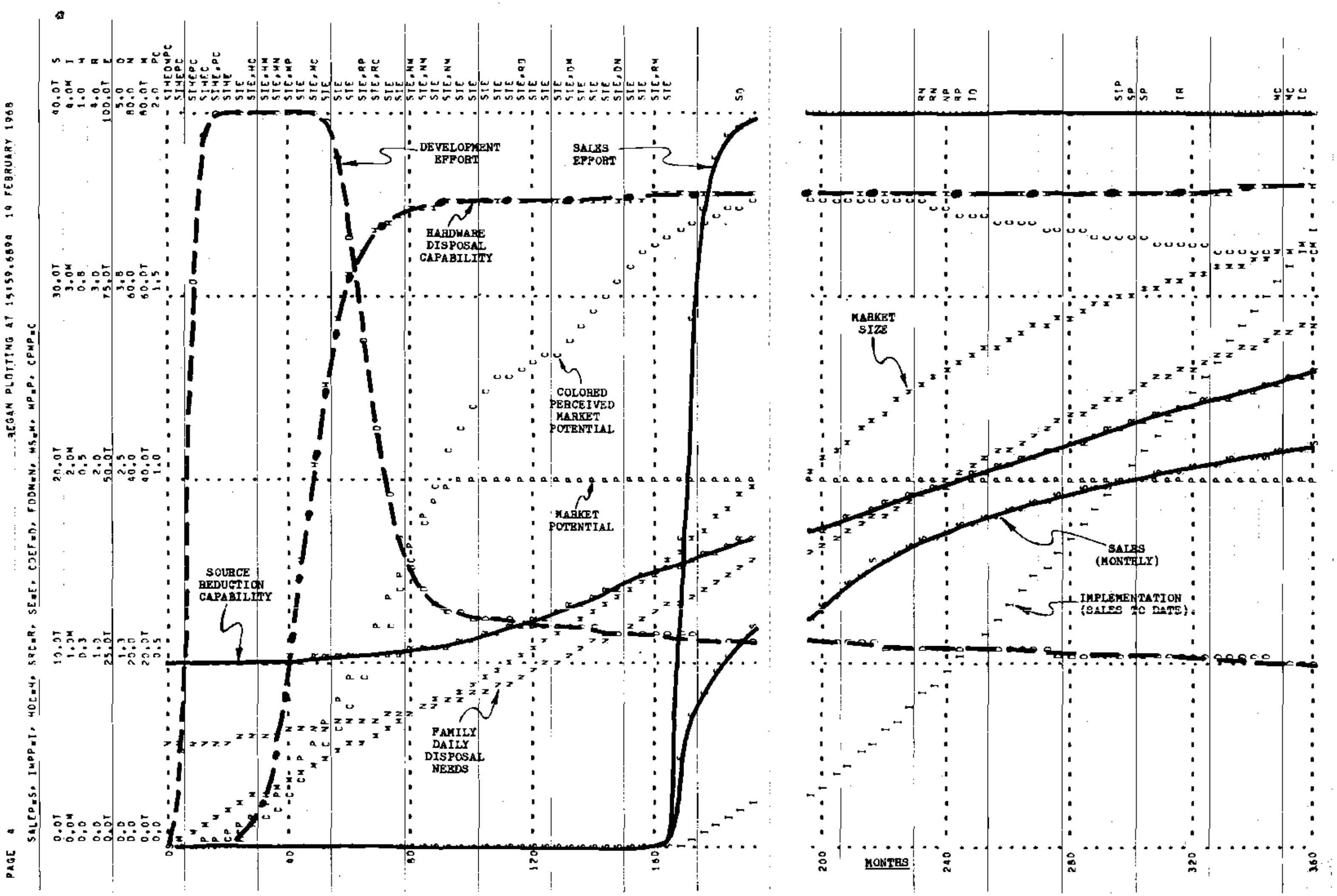

Figure 41. Run #3 - Plot #1.

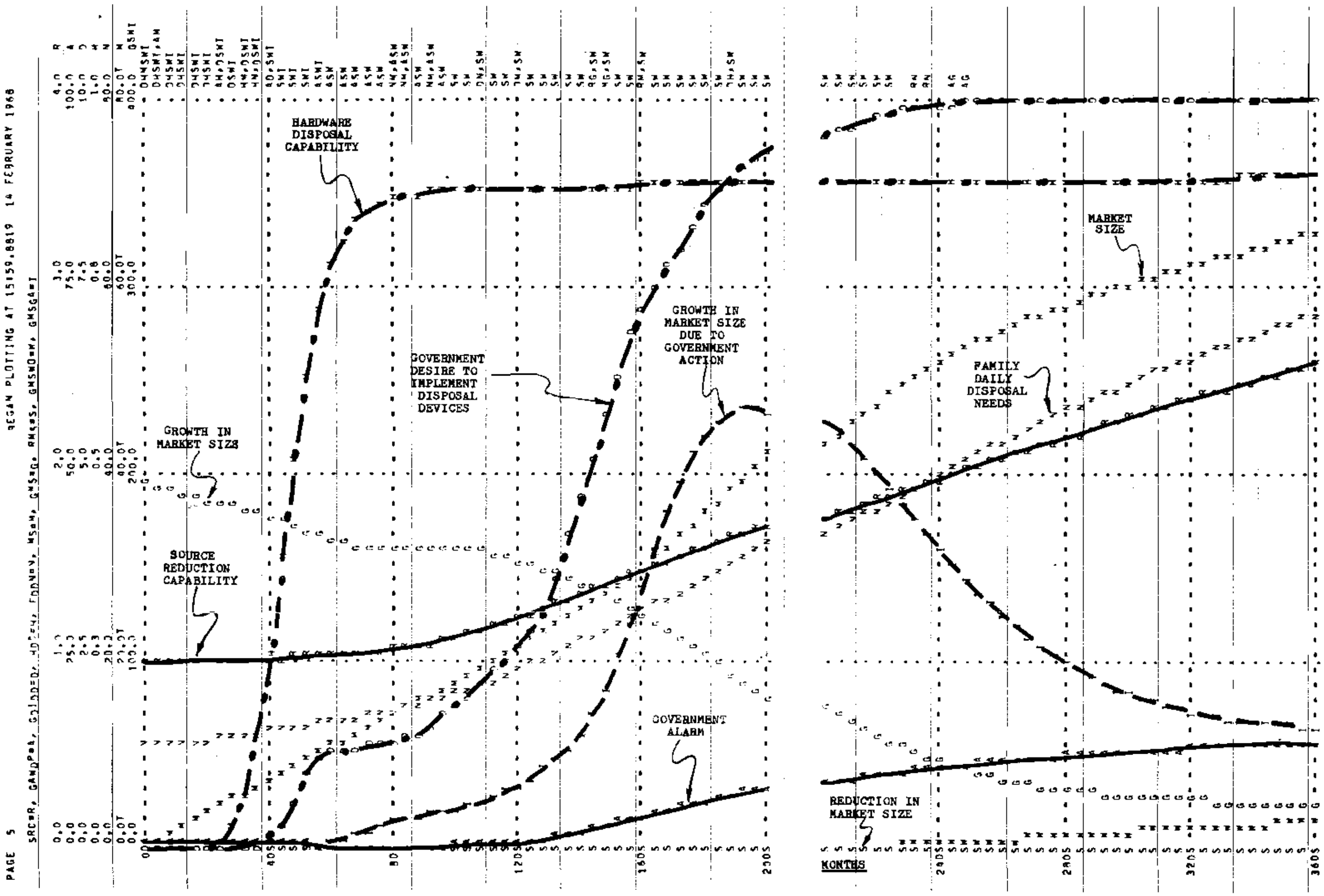

Figure 42. Run #3 - Plot #2.

disposal devices begins to rise earlier and rises more steeply, reaching a value of 7.5 more than five years sooner than in run #1. The growth in market size due to this government desire is also shifted to the left on the time axis, the maximum rate of growth occurring nearly seven years earlier than in run #1.

In general, the behavior is far more favorable from Whirlpool's point of view. The market for the product grows steadily, and there are no danger periods during which the success of the new product is in doubt. Furthermore, even if the product had never been accepted as satisfactory by the government, Whirlpool would not have risked the consequences of alienating the government or the public by attempting to market an unacceptable product.

Whirlpool exercised a considerable degree of control over the entire system in run #3. By influencing the government's reactions to the waste disposal problem and its possible solutions, Whirlpool obtained help from the government in developing a market for the disposal appliance.

The Controlling Feedback Loops

All 26 of the model's feedback loops were active during the three simulation experiments. As is usually the case in complex feedback systems, however, relatively few of the loops were of major importance in controlling the mode of system behavior. A simplified conceptual model showing the four most important control loops appears in Figure 43.

The importance of government reactions is apparent in the simplified conceptual model. The net effect of the reaction is determined

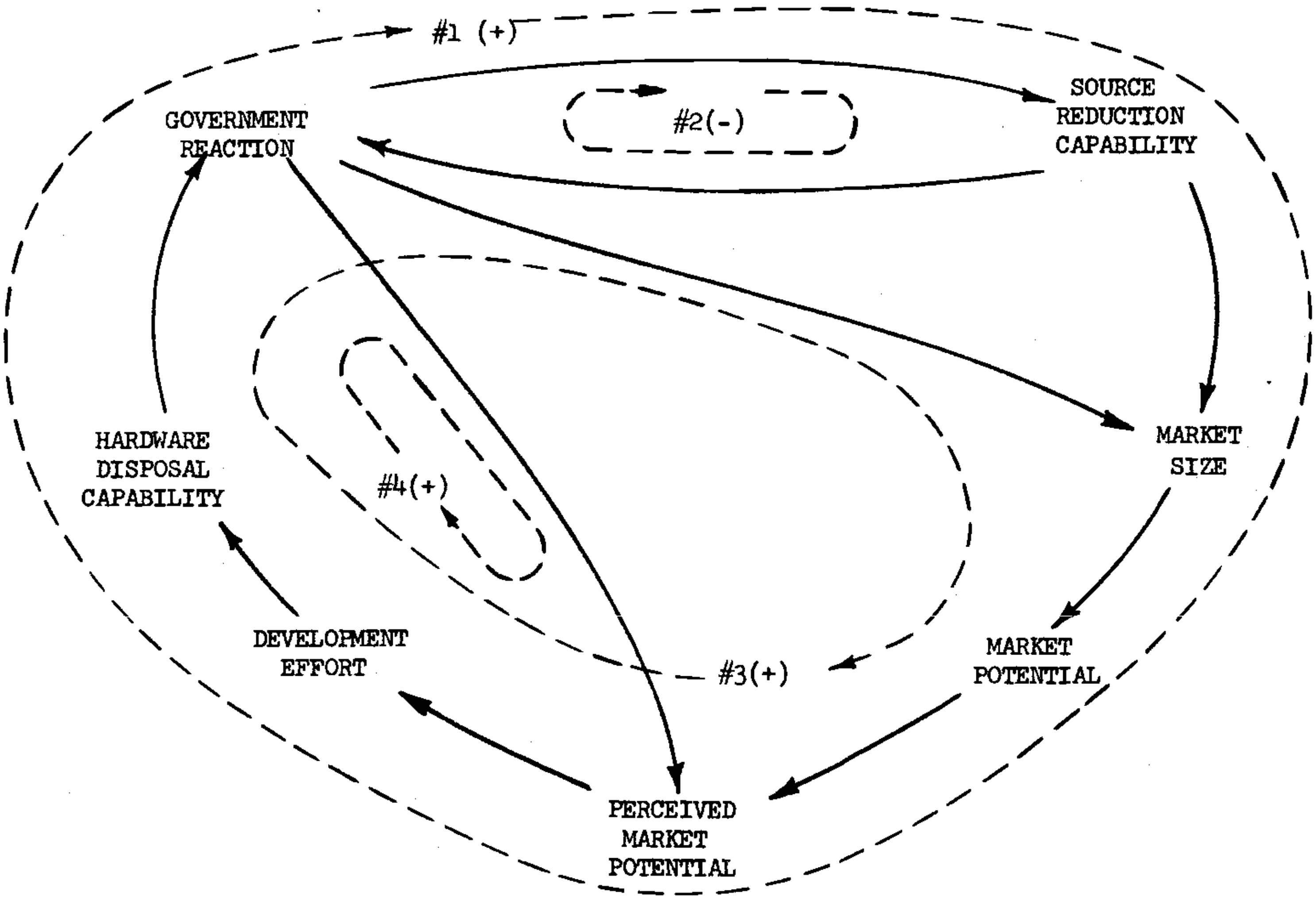

Figure 43. The Controlling Loops.

by the relative strengths of the government's alarm over the waste problem ans the government's desire to implement disposal devices.

When alarm over the problem is the stronger reaction, loop #2 becomes dominant in controlling the system. Loops #1 and #4 serve only to decrease the perceived market potential, which stifles development effort. The resulting inability to cause increases in hardware disposal capability suppresses loop #3. Only a growth in the waste problem due to exogenous increases in population and retail buying power can eventually cause an increase in perceived market potential, which can lead to increases in hardware disposal capability and a change in the government's reaction. Notice here that Whirlpool would be entirely dependent on exogenous inputs over which Whirlpool has no control.

The results of run #3 showed the effects of isolating loop #4 from the remainder of the system during the initial stages of development. The effective perceived market potential depends entirely on government reactions, and the product's capability is developed regardless of the actual market potential for the product. The development of the product ensures the government's desire to implement the device and the relief of government alarm over the problem. Consequently, loop #2 is suppressed, and loops #1 and #3 become dominant, causing a spiralling growth in the market. In effect, the development of the product perpetuates the waste problem and causes the development of a market for the product.

Comments on the Results

Again it must be emphasized that the results that have been shown in the simulation experiments are by no means a prediction or forecast of either the values to be attained by variables in the real world system or the exact timing of events in the real world system. These experiments should be interpreted as illustrating the behavioral mode which can be expected of this system and the types of change in this behavioral mode that can be expected with changes in Whirlpool's strategy.

CHAPTER VI

CONCLUSIONS

The results of this research are summarized below.

(1) The problem of solid waste disposal is great in magnitude and complexity, and research directed at coping with the problem is still in its early stages.

(2) A general lack of public concern has been characteristic of the waste problem.

(3) The problem of solid waste disposal may be attacked in one or more of several different ways.

(4) The government at local, state, and national levels will play a large part in determining the method of attacking the solid waste disposal problem.

(5) If Whirlpool is to be successful in marketing a disposal appliance, the problem of solid waste disposal must be perpetuated.

(6) Although there are great needs in the area of solid waste disposal, the market for disposal devices does not presently exist in the form with which Whirlpool is accustomed to dealing.

(7) Government acceptance of the product is extremely important, since the product will attempt to treat a public environment problem.

(8) A favorable reaction on the part of the government to the hardware capability of the product can contribute greatly to the development of a market for the product, whereas an unfavorable

government reaction can effectively render the product unsalable.

(9) Whirlpool can exercise a significant degree of control over this complex system, especially by influencing the government's reactions to the waste disposal problem and its possible solutions.

CHAPTER VII

RECOMMENDATIONS

The decision as to whether or not to undertake this new product venture can and must be made only by Whirlpool management. The role of leadership within the industry is by no means new to Whirlpool. Managerial intelligence, judgment, and experience are irreplaceable in this decision-making process.

Should the decision be made to undertake the development and marketing of the disposal appliance, several recommendations are offered.

(1) Research should begin as soon as practicable in conjunction with the Public Health Service to determine the most acceptable mode of operation for the disposal appliance and the standards which must be met by the devie. The concept of regionwide usage of the appliance should be of importance in this research. The effects on other environmental problems, such as water pollution, air pollution, and limited existing sewage capacity, must be of constant concern. There are possibilities for federal support for this research under the provisions of Section 204 of the Solid Waste Disposal Act. The actual physical development of the product should begin only after the above questions have been given due consideration. The Public Health Service and other appropriate government agencies should be help informed of the progress of all research, and their constructive criticism and evaluation should be

solicited. This approach should give the government a sense of involvement, if not a sense of commitment, to Whirlpool's efforts.

(2) During the stages of development just preceding the introduction of the product to the market, some effort may be made to inform the public of the seriousness of the waste disposal problem and of Whirlpool's efforts to find a workable and desirable solution to the problem. This educational campaign should not be premature, since an aroused public may press for government restrictions against the source industries before Whirlpool is able to introduce its appliance.

(3) Since the government is keenly aware of the waste disposal problem, it should be considered as a giant potential customer for the new product. The appliance may well be introduced to the public through implementation in federally financed housing developments, model city programs, and other construction subject to government imposed standards.

(4) Some preliminary considerations should be given to the appropriate type of marketing outlet for the product. Experience with conventional garbage disposal units has shown that the majority of the units are sold through plumbing contractors. Only a small fraction of the units are sold through retail appliance stores. The physical characteristics of Whirlpool's product and the problems involved in its installation will largely determine the appropriate outlet for the product.

(5) As time passes, the system perspective on this problem will undoubtedly change greatly. Once the product has been successfully introduced to the market, the considerations involving government action,

source reduction capability, and public acceptance may be less important. On the other hand, considerations such as competitive strategy, production-inventory-distribution interactions, and production capacity acquisition may take on extreme importance. The philosophy and techniques of industrial dynamics can be of continuing value to the managers of Whirlpool as an aid in understanding the dynamics of their complex systems.

APPENDIX A

Sample Questionnaire

COMPANY: ____

(1) Is your company aware of the problem of solid waste disposal? Yes_____ No_____

(2) Is your company carrying on any research to develop packaging materials or techniques which will reduce the problem of trash disposal in the home or industry? (Or research in other areas which may leas to such developments)
Yes_____ No_____
If Yes, please describe briefly, if possible:

____

____

____

____

(3) Has your company received any form of encouragement from any governmental body to conduct research as described above?
Yes_____ No_____

(4) Does your company anticipate future federal legislation to regulate the packaging industry in an attempt to allieviate the solid waste disposal problem? Yes_____ No_____
If Yes, please describe briefly if possible:

____

____

____

____

Packaging Companies Contacted

American Can Company
New York, New York

Champion Papers, Inc.
Hamilton, Ohio

Consolidated Papers, Inc.
Wisconsin Rapids, Wisconsin

Container Corporation of America
Chicago, Illinois

Continental Can Company, Inc.
New York, New York

Crown Zellerbach Corporation
San Francisco, California

Ekco Containers, Inc.
Wheeling, Illinois

Fibreboard Paper Products Corporation
San Francisco, California

Inland Container Corporation
Indianapolis, Indiana

International Paper Company
New York, New York

Owens - Illinois
Toledo, Ohio

Packaging Corporation of America
Evanston, Illinois

Riegal Paper Corporation
New York, New York

Union Camp Corporation
New York, New York

APPENDIX B

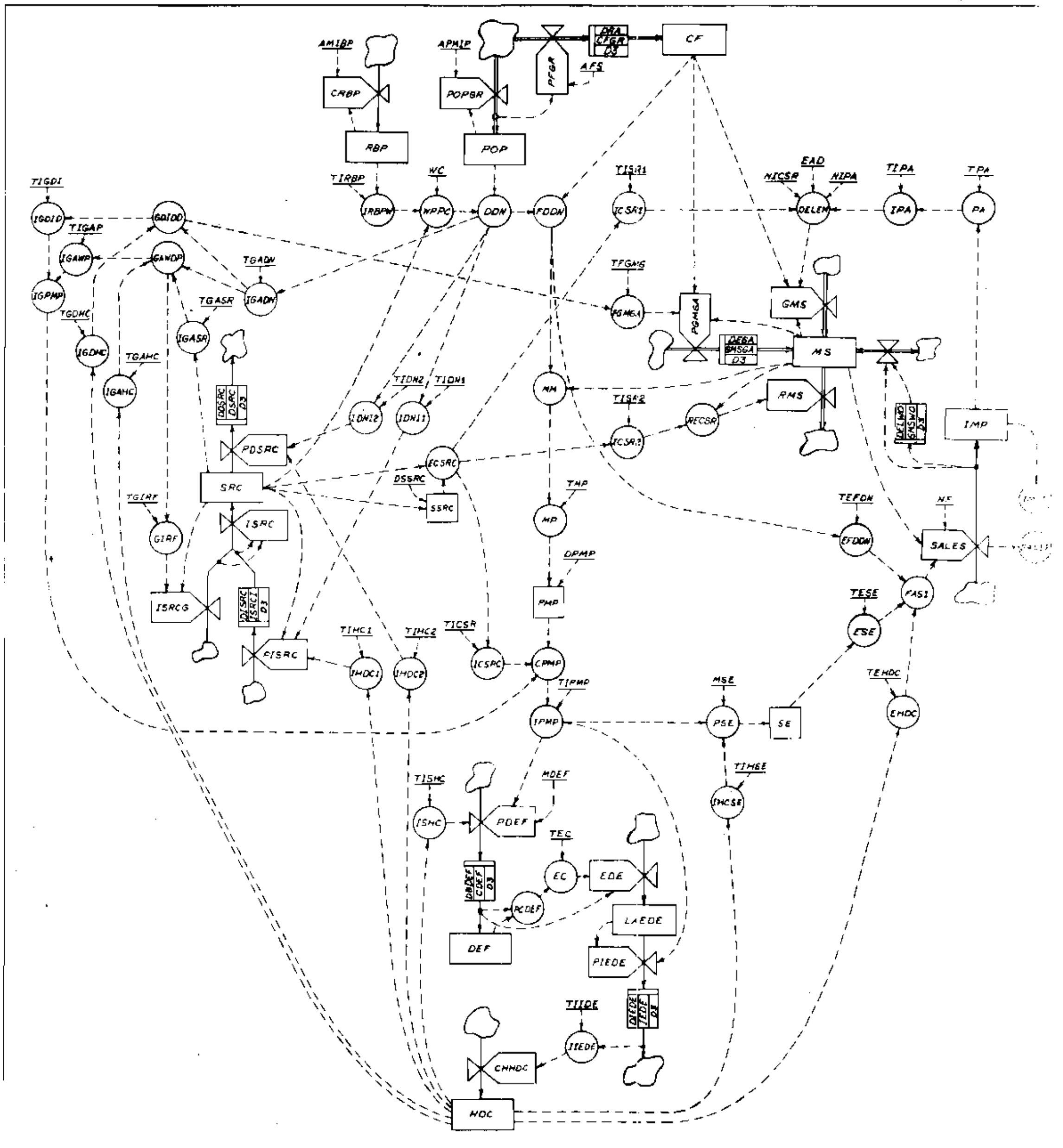

Figure 44. Complete Flow Diagram.

Glossary of Identifiers

(1) The identifiers of all variables used in the model are listed in alphabetical order.

(2) The variable type is given in the column labeled "Type" using the following symbols.

L - Level

R - Rate

A - Auxiliary

C - Constant

S - Supplementary

(3) The section of the model in which the variable is defined is dhown in the "Def." column using the following number code.

1 - Population, Families, and Retail Buying Power

2 - Daily Disposal Needs

3 - Government Reactions

4 - Market Size

5 - Market Potential

6 - Development Effort

7 - Hardware Disposal Capability

8 - Source Reduction Capability

9 - Sales Effort

10 - Sales and Implementation

11 - Public Acceptance

Identifier	Interpretation	Type	Def.
AFS	Average Family Size	C	1
AMIBP	Average percentage Monthly Increase in Buying Power	C	1
APMIP	Average Percentage Monthly Increase in Population	C	1
CDEF	Change in Development EFort	R	6
CF	Current Families	L	1
CFGR	Current Family Growth	R	1
CHHDC	CHange in Hardware Disposal Capability	R	7
CPMP	Colored Perceived Market Potential	A	5
CRBP	Change in Retail Buying Power	R	1
DBDEF	Delay in Beginning Development EFfort	C	6
DDN	Daily Disposal Needs	A	2
DDSRC	Delay in Decreasing Source Reduction Capability	C	8
DEF	Development EFfort	L	6
DEGA	DElay in implementing Government Action	C	4
DELEM	DELay in Entering the Market	C	4
DELWO	DELay to Wear Out	C	4
DIEDE	Delay in Implementing Effective Development Effort	C	7
DISRC	Delay in Increasing Source Reduction Capability	C	8
DPMP	Delay in Perceiving Market Potential	C	5
DRA	Delay in Reaching Adulthood	C	1
DSRC	Decrease in Source Reduction Capability	R	8
DSSRC	Delay in Smoothing Source Reduction Capability	C	4

Identifier	Interpretation	Type	Def.
EAD	Effective Average Delay	C	4
EC	Effectiveness Coefficient	A	7
ECSRC	Experienced Change in Source Reduction Capability	A	4
EDE	Effective Development Effort	R	7
EFDDN	Effect of Family Daily Disposal Needs	A	10
EHDC	Effect of Hardware Disposal Capability	A	10
EIPPD	Effective Impact of Perceived market Potential on Development effort (run #3 only)	A	6
EIPPS	Effective Impact of Perceived market Potential on Sales effort (run #3 only)	A	9
ESE	Effect of Sales Effort	A	10
FAS1	Factors Affecting Sales	A	10
FDDN	Family Daily Disposal Needs	A	2
FGMGA	Fractional Growth in the Market due to Government Action	A	4
GAWDP	Government Alarm over the Waste Disposal Problem	A	3
GDIDD	Government Desire to Implement Disposal Devices	A	3
GIRF	Government Imposed Reduction Factor	A	8
GMS	Growth in Market Size	R	4
GMSGA	Growth in Market Size due to Government Action	R	4
GMSWO	Growth in Market Size due to Wear Out	R	4
HDC	Hardware Disposal Capability	L	7
ICSRC	Impact of Change in Source Reduction Capability	A	5

Identifier	Interpretation	Type	Def.
ICSR1	Impact of Change in Source Reduction capability #1	A	4
ICSR2	Impact of Change in Source Reduction capability #2	A	4
IDNI1	Impact of daily Disposal Needs on Industry #1	A	8
IDNI2	Impact of daily Disposal Needs on Industry #2	A	8
IEDE	Implemented Effective Development Effort	R	7
IGADN	Impact on Government Alarm of daily Disposal Needs	A	3
IGAHC	Impact on Government Alarm of Hardware disposal Capability	A	3
IGASR	Impact on Government Alarm of Source Reduction capability	A	3
IGAWP	Impact of Government Alarm over the Waste disposal Problem	A	5
IGDHC	Impact on Government Desire of Hardware disposal Capability	A	3
IGDID	Impact of Government Desire to Implement disposal Devices	A	5
IGPMP	Impact of the Government on Perceived Market Potential	A	5
IHCSE	Impact of Hardware disposal Capability on Sales Effort	A	9
IHDC1	Impact of Hardware Disposal Capability #1	A	8
IHDC2	Impact of Hardware Disposal Capability #2	A	8
IIEDE	Impact of Implemented Effective Development Effort	A	7
IMP	IMPlementation	L	10
IMPP	IMPlementation for Plotting	S	10

Identifier	Interpretation	Type	Def.
IPA	Impact of Public Acceptance	A	4
IPMP	Impact of Perceived Market Potential	A	6
IRBPW	Impact of Retail Buying Power on Waste	A	2
ISHC	Impact of Saturation of Hardware disposal Capability	A	6
ISRC	Increase in Source Reduction Capability	R	8
ISRCI	Increase in Source Reduction Capability due to Industry	R	8
ISRCG	Increase in Source Reduction Capability due to the Government	R	8
LAEDE	Level of Available Effective Development Effort	L	7
MDEF	Maximum Development EFfort	C	6
MM	Market Magnitude	A	5
MP	Markter Potential	A	5
MS	Market Size	L	4
MSE	Maximum Sales Effort	C	9
NICSR	Normal Impact of Changes in Source Reduction capability	C	4
NIPA	Normal Impact of Public Acceptance	C	4
NF	Normalizing Factor	C	10
PA	Public Acceptance	A	11
PCDEF	Percentage Change in Development EFfort	A	7
PDEF	Planned Development EFfort	R	6
PDSRC	Planned Decrease in Source Reduction Capability	R	8
PFGR	Potential Family Growth	R	1

Identifier	Interpretation	Type	Def.
PGMGA	Planned Growth in Market size due to Government Action	R	4
PIEDE	Planned Implementation of Effective Development Effort	R	7
PISRC	Planned Increase in Source Reduction Capability	R	8
PMP	Perceived Market Potential	L	5
POP	POPulation	L	1
POPGR	POPulation GRowth	R	1
PSE	Planned Sales Effort	R	9
RBP	Retail Buying Power	L	1
RECSR	Reduction in market size due to Experienced Change in Source Reduction Capability	A	4
RMS	Reduction in Market Size	R	4
SALES	SALES	R	10
SALEP	SALEs for Plotting	S	10
SE	Sales Effort	L	9
SRC	Source Reduction Capability	L	8
SSRC	Smoothed Source Reduction Capability	L	4
TEC	Table of EC versus PCDEF	C	7
TEFDN	Table of EFDDN versus FDDN	C	10
TEHDC	Table of EHDC versus HDC	C	10
TESE	Table of ESE versus SE	C	10
TFGMG	Table of FGMGA versus GDIDD	C	4
TGADN	Table of IGADN versus DDN	C	3
TGAHC	Table of IGAHC versus HDC	C	3

Identifier	Interpretation	Type	Def.
TGASR	Table of IGASR versus SRC	C	3
TGDHC	Table of IGDHC versus HDC	C	3
TGIRF	Table of GIRF versus GAWDP	C	8
TICSR	Table of ICSRC versus ECSRC	C	5
TIGDI	Table of IGDID versus GDIDD	C	5
TIGAP	Table of IGAWP versus GAWDP	C	5
TIHSE	Table of IHCSE versus HDC	C	9
TLDN1	Table of IDNI1 versus DDN	C	8
TIDN2	Table of IDNI2 versus DDN	C	8
TIHC1	Table of IHDC1 versus HDC	C	8
TIHC2	Table of IHDC2 versus HDC	C	8
TIIDE	Table of IIEDE versus IEDE	C	7
TIPA	Table of IPA versus PA	C	4
TIPMP	Table of IPMP versus CPMP	C	6
TIRBP	Table of IRBPW versus RBP	C	2
TISHC	Table of ISHC versus HDC	C	6
TISR1	Table of ICSR1 versus ECSRC	C	4
TISR2	Table of ICSR2 versus ECSRC	C	4
TMP	Table of MP versus MM	C	5
TPA	Table of PA versus IMP	C	11
WC	Waste Coefficient	C	2
WPPC	Waste Produced Per Capita	A	2

APPENDIX C

Test Runs

The model was tested in five sections. The sections are shown in Figure 45. Two runs were made on each section. The first run was made under conditions very close to the initial conditions of the model, and the second run was made under conditions corresponding to a much greater magnitude of the waste problem.

The results of the test runs are shown in Figures 46 through 59.

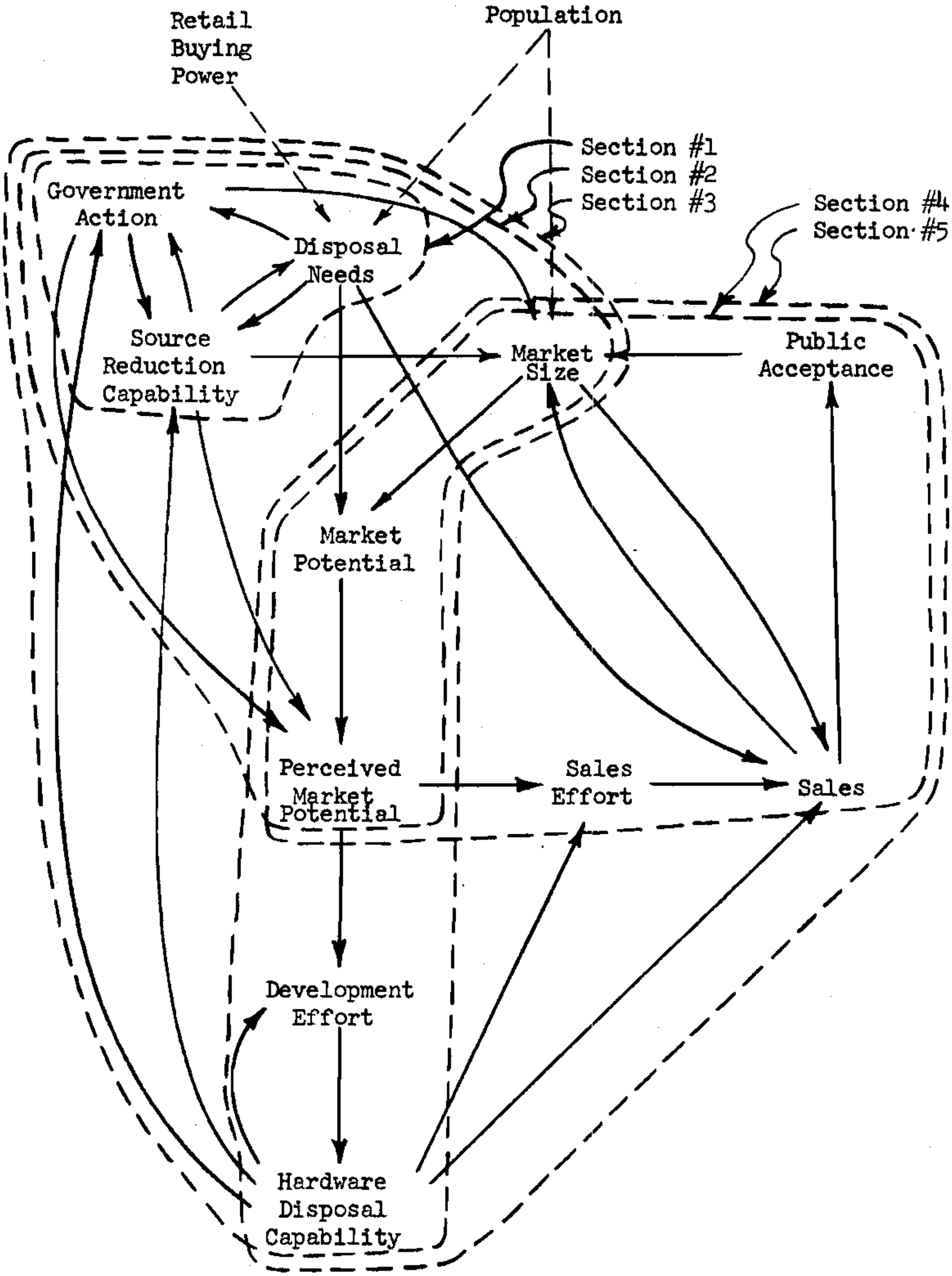

Figure 45. Test Sections.

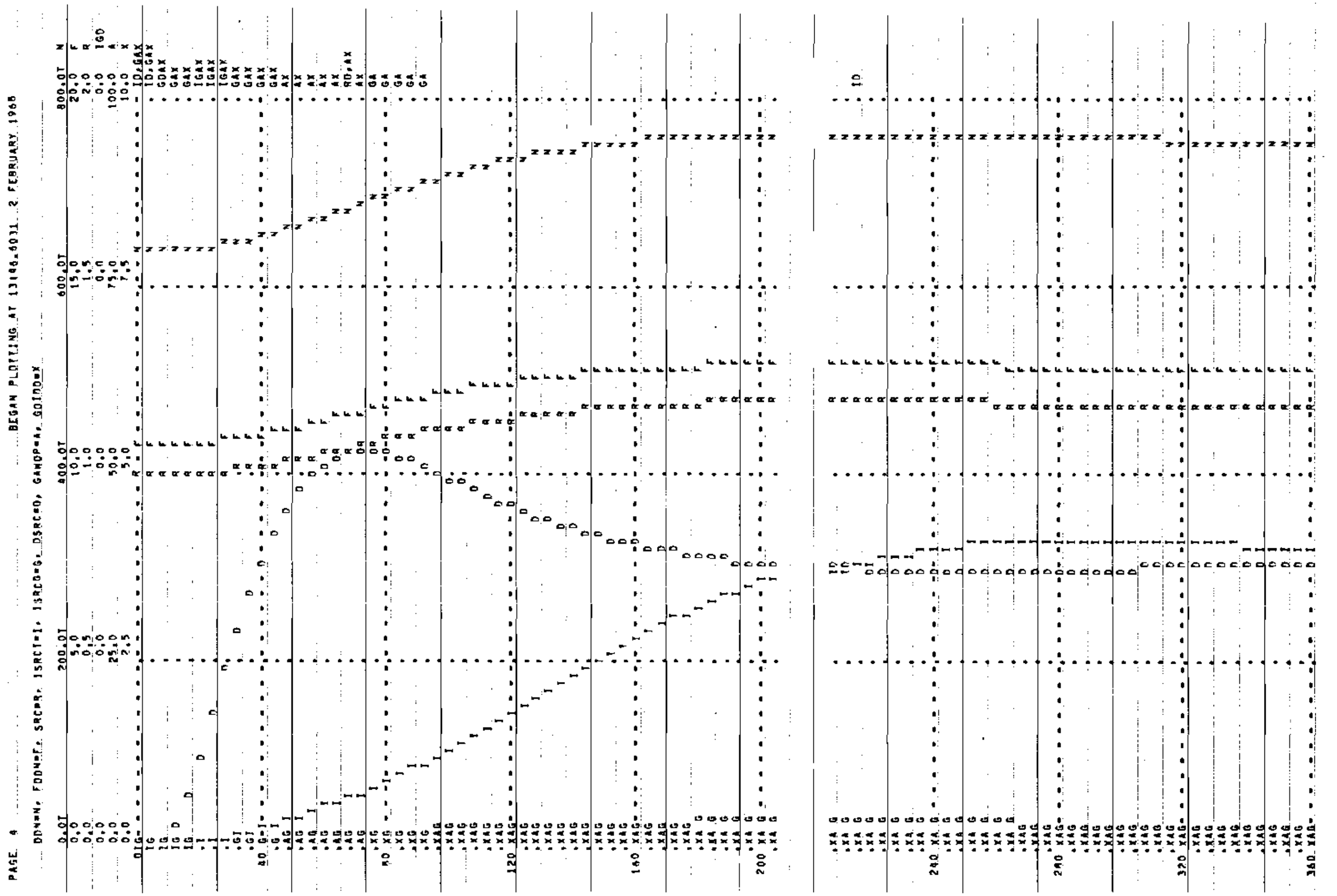

Figure 46. Section #1 - Run #1.

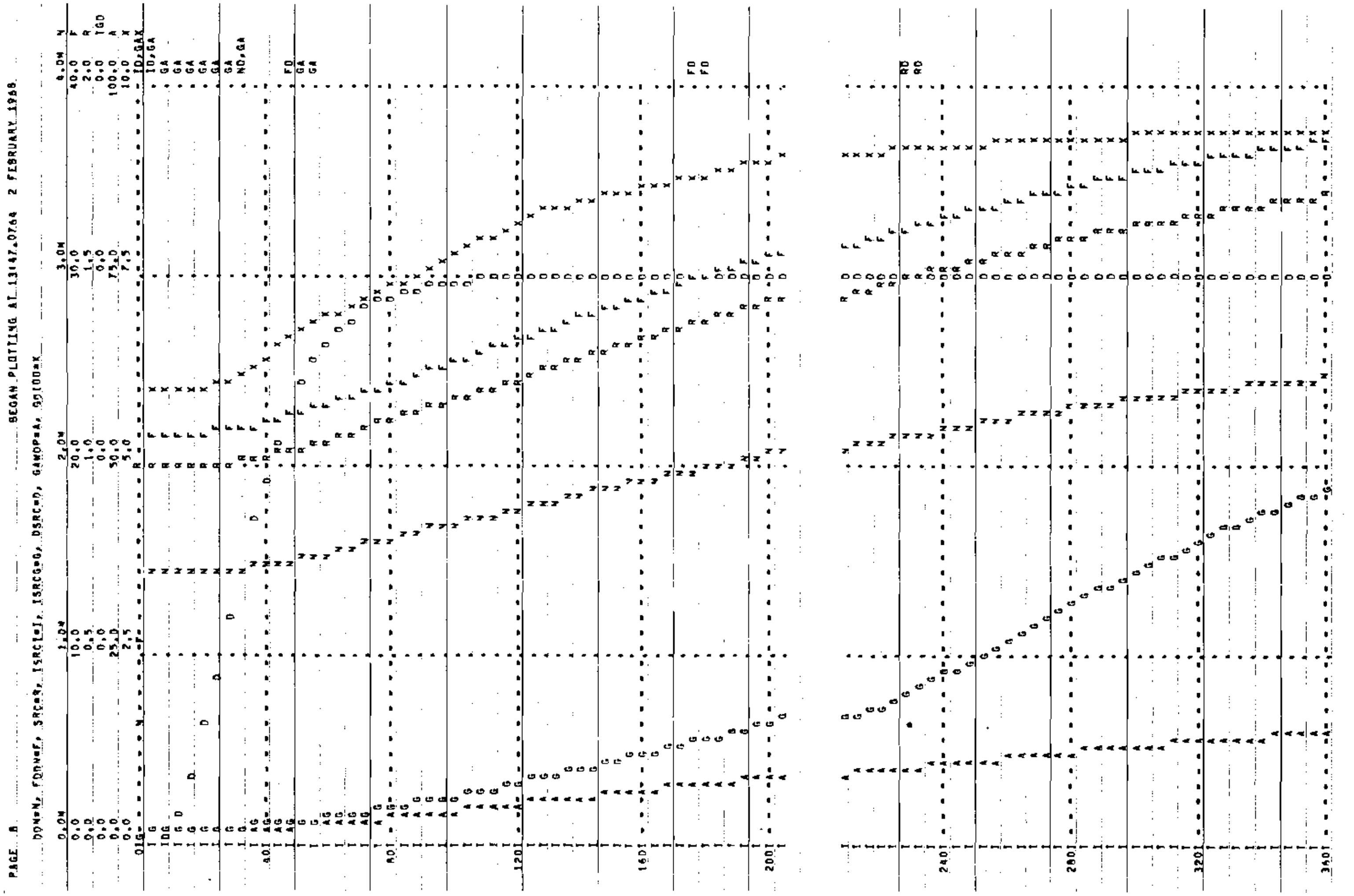

Figure 47. Section #1 - Run #2.

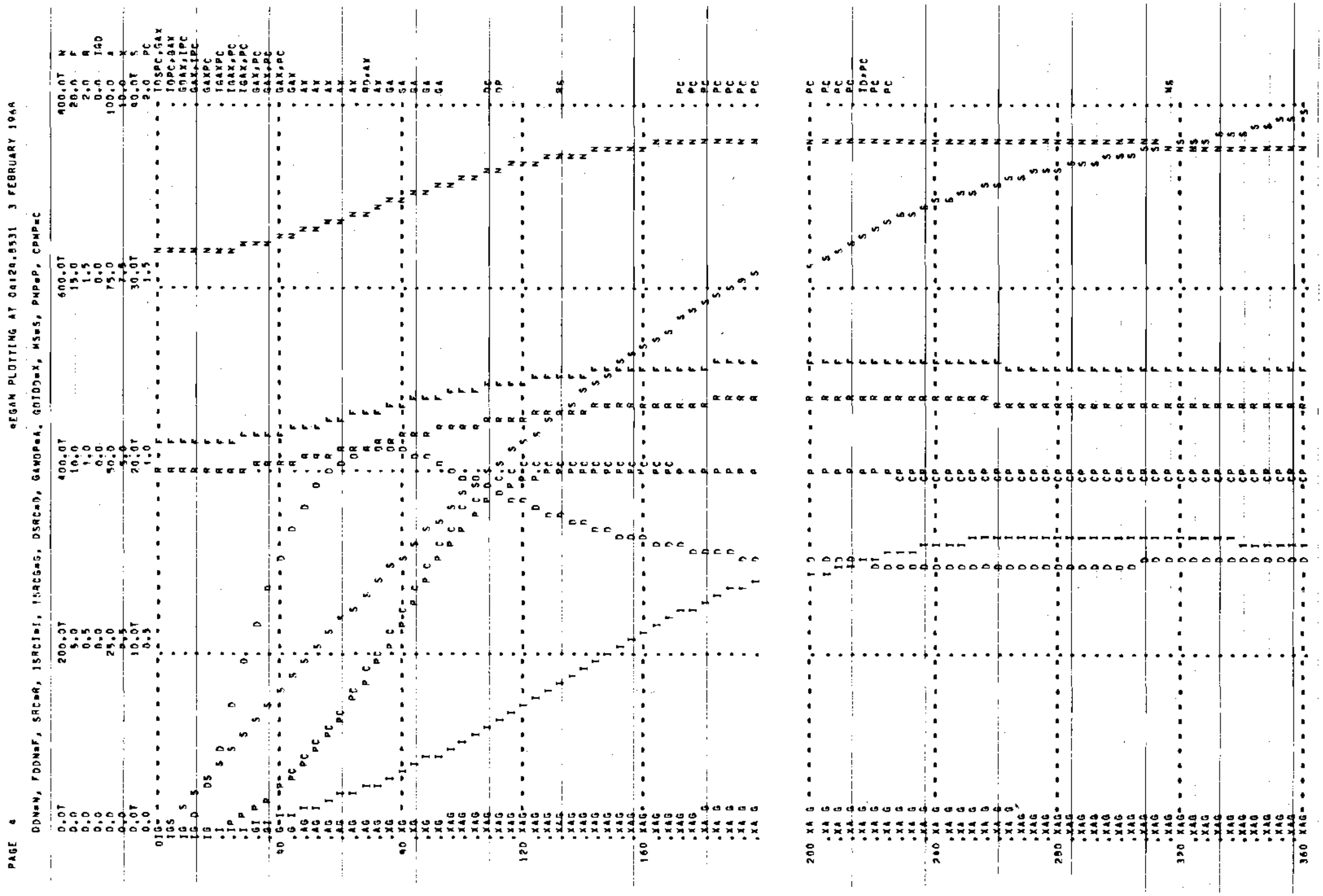

Figure 48. Section #2 - Run #1 - Plot #1.

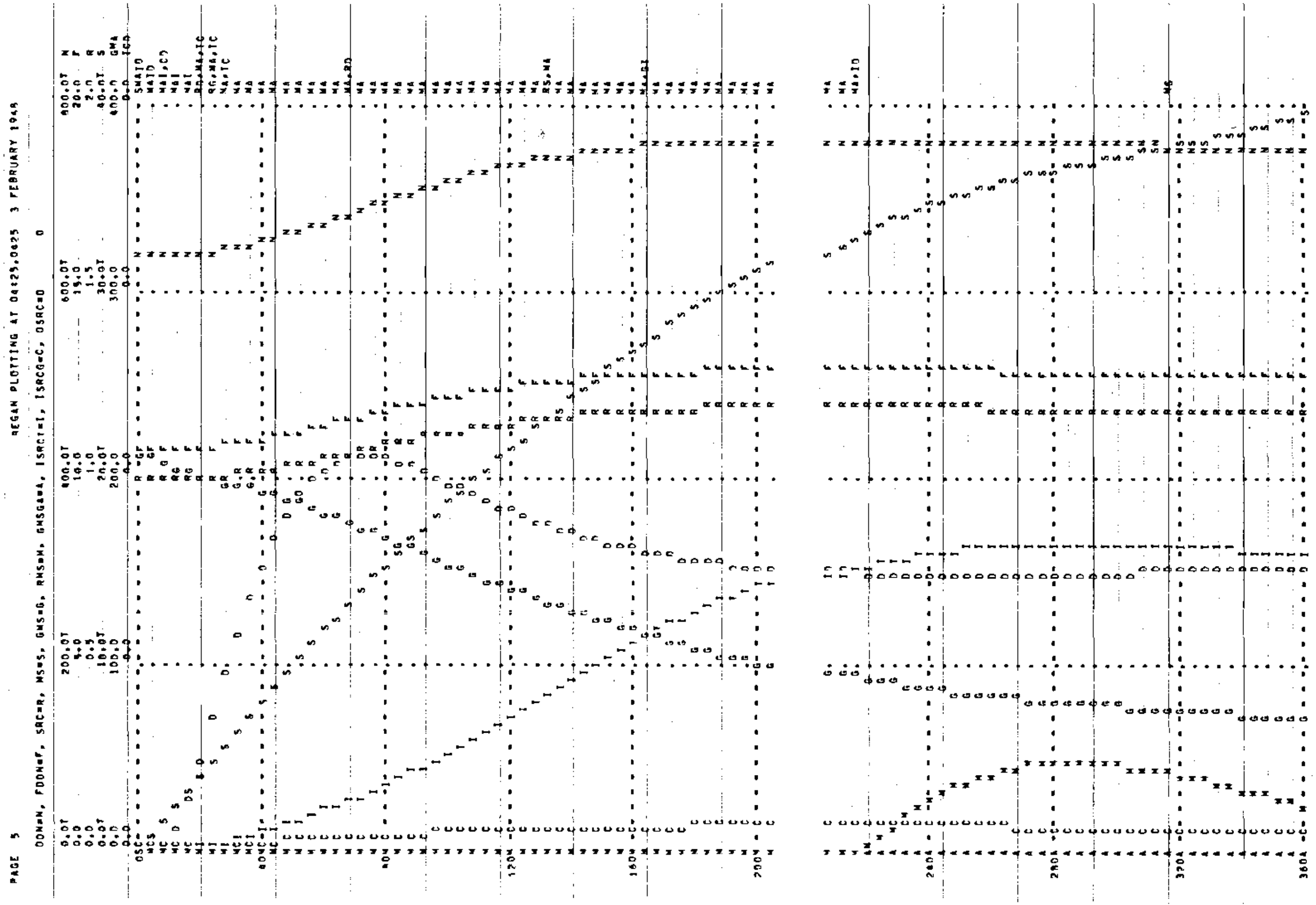

Figure 49. Section #2 - Run #1 - Plot #2.

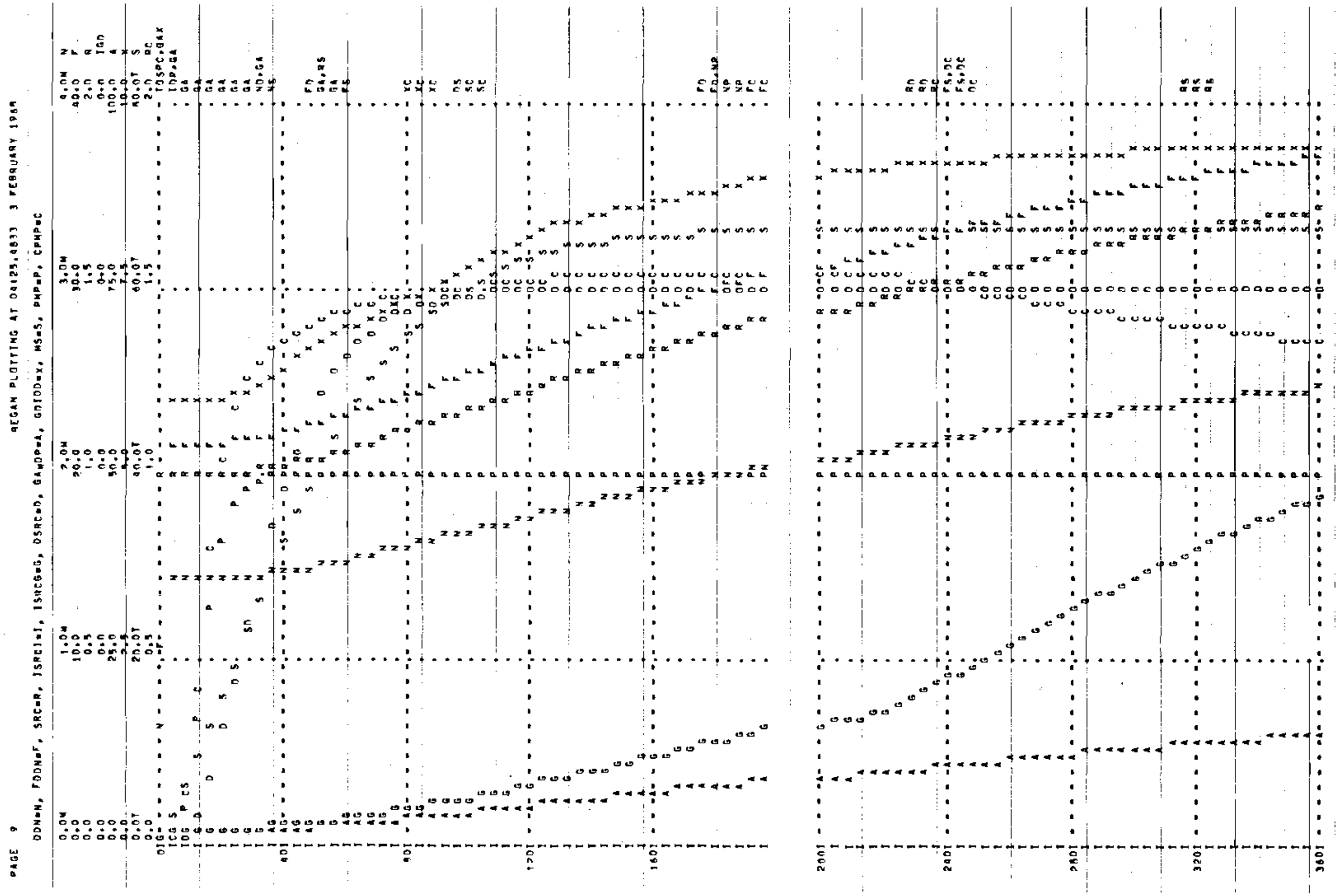

Figure 50. Section #2 - Run #2 - Plot #1.

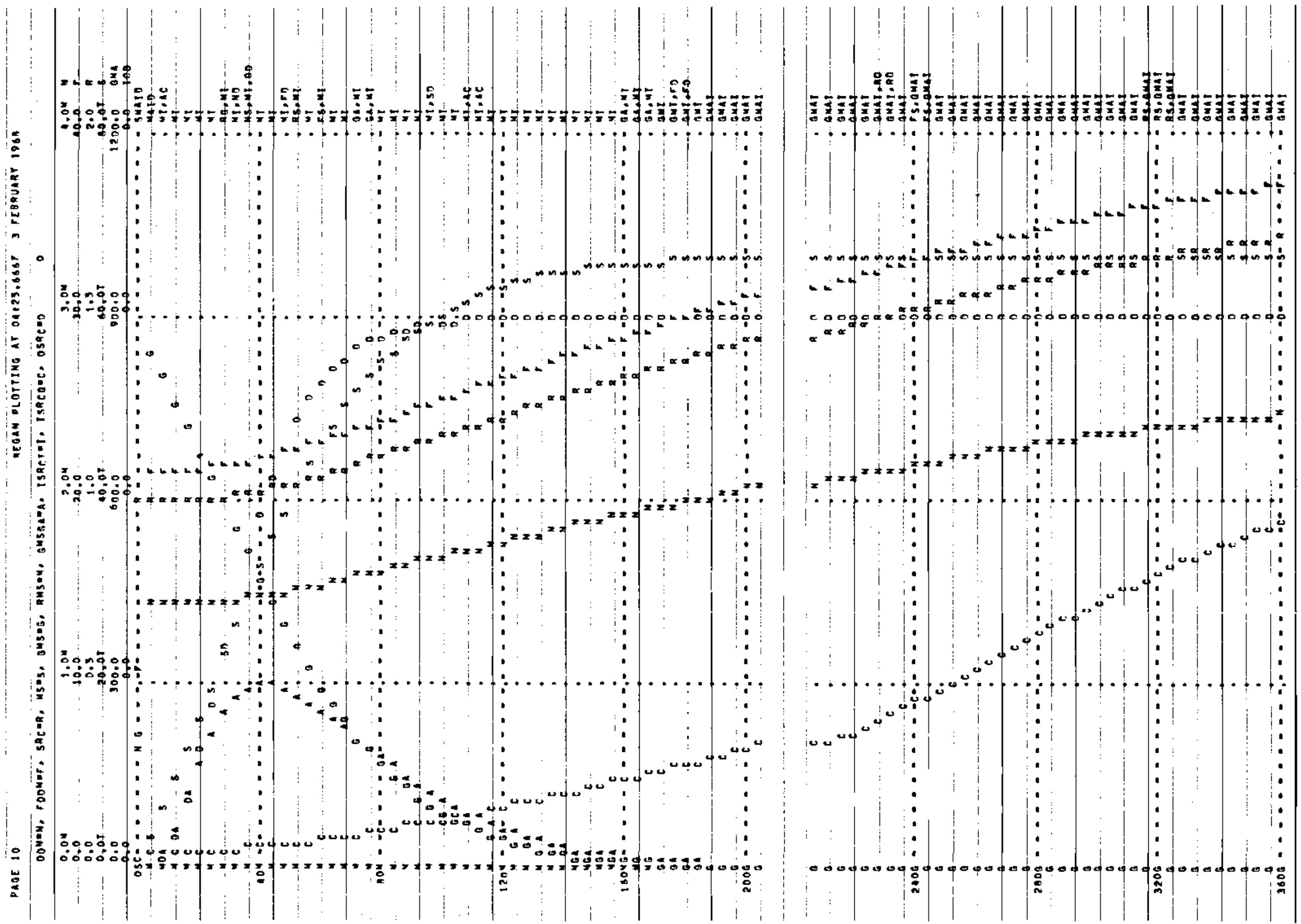

Figure 51. Section #2 - Run #2 - Plot #1.

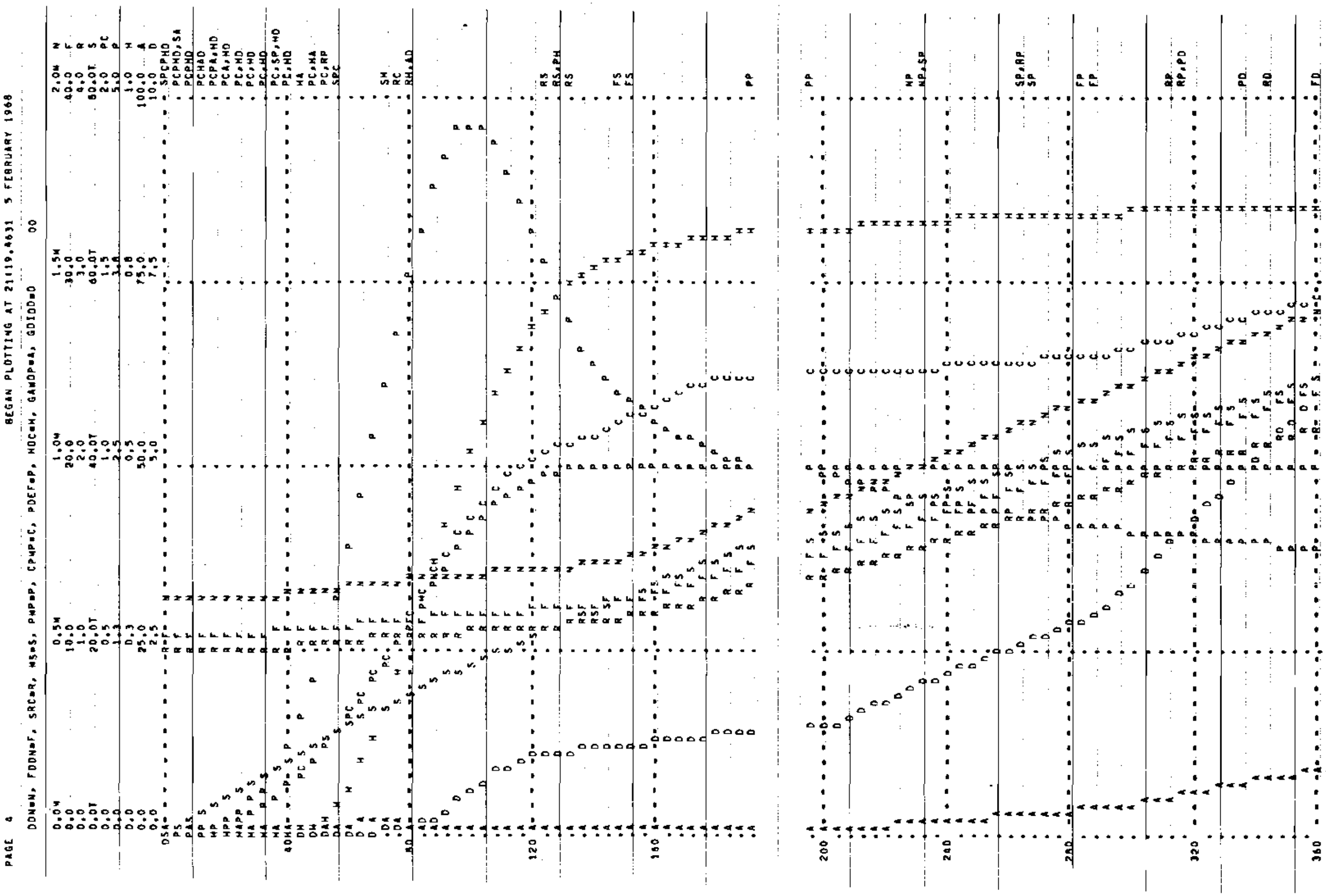

Figure 52. Section #3 - Run #1 - Plot #1.

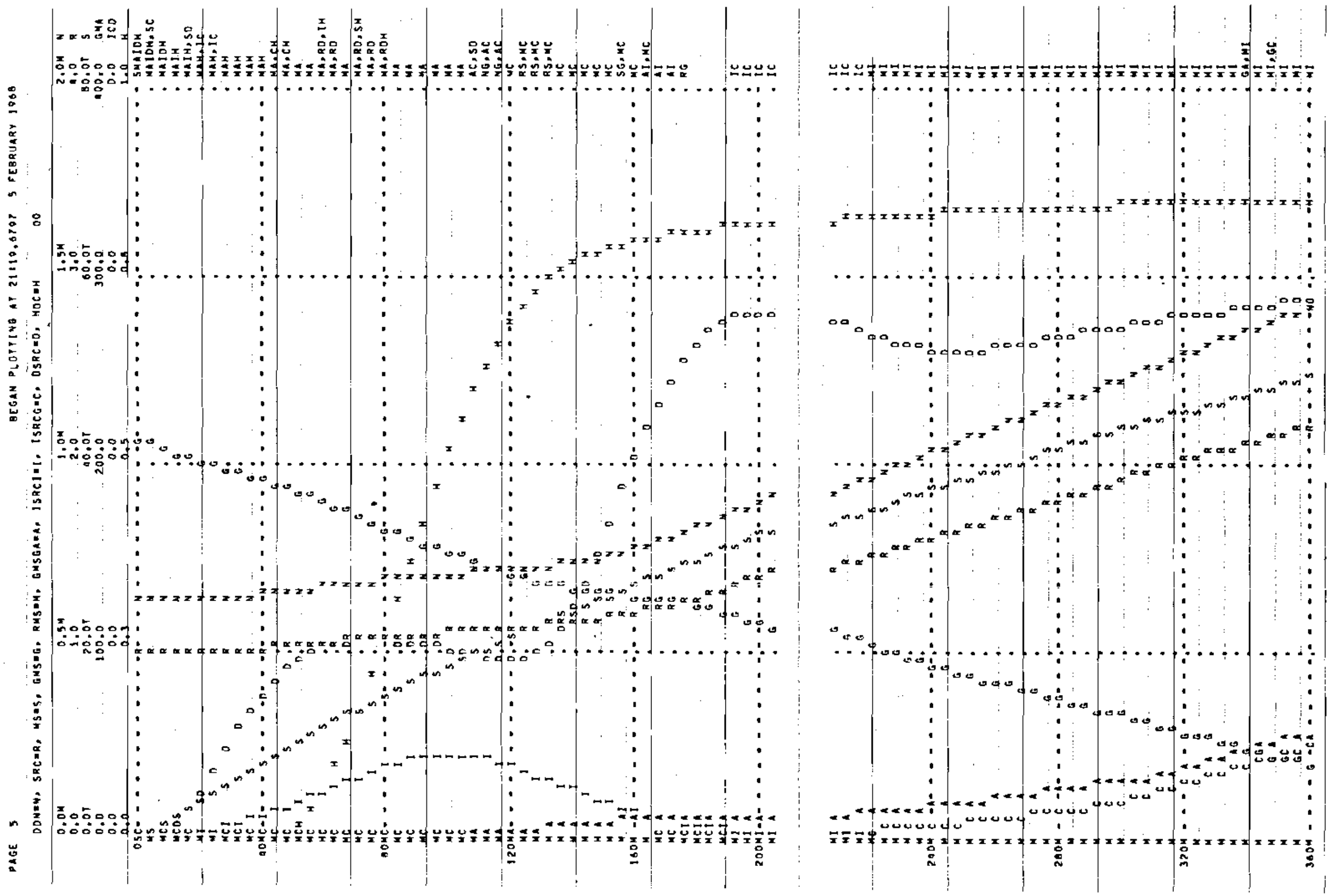

Figure 53. Section #3 - Run #1 - Plot #2.

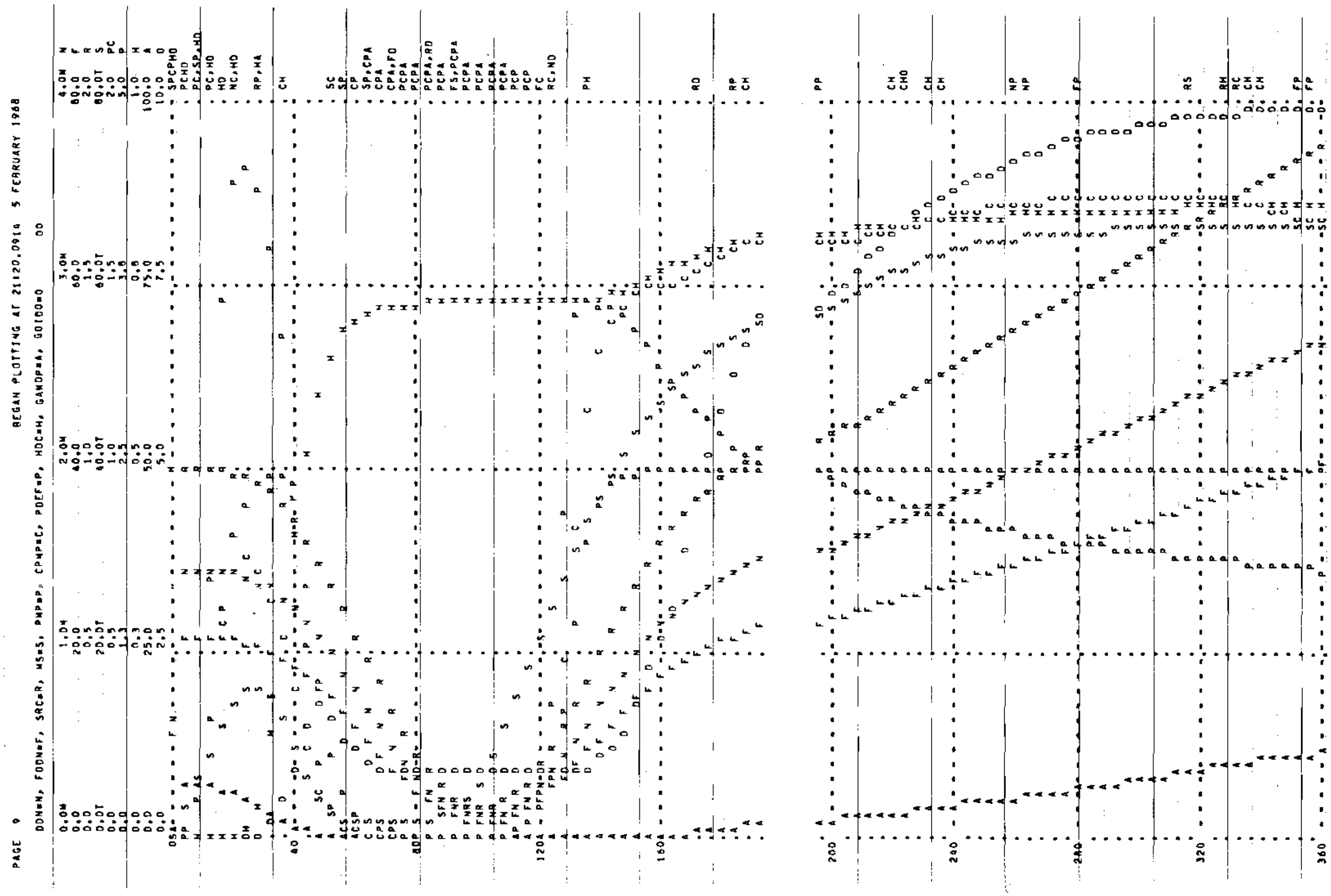

Figure 54. Section #3 - Run #2 - Plot #1.

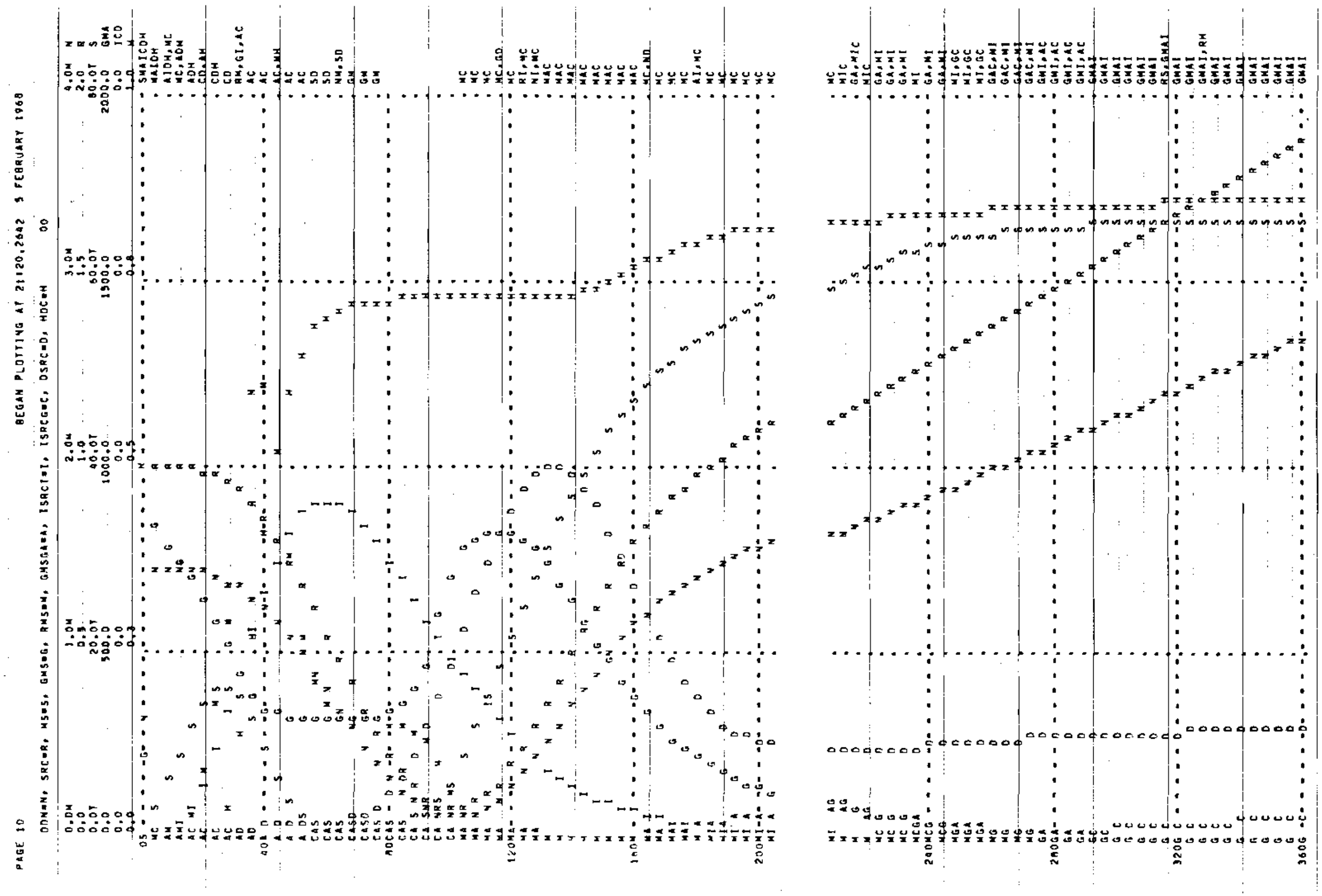

Figure 55. Section #3 - Run #2 - Plot #2.

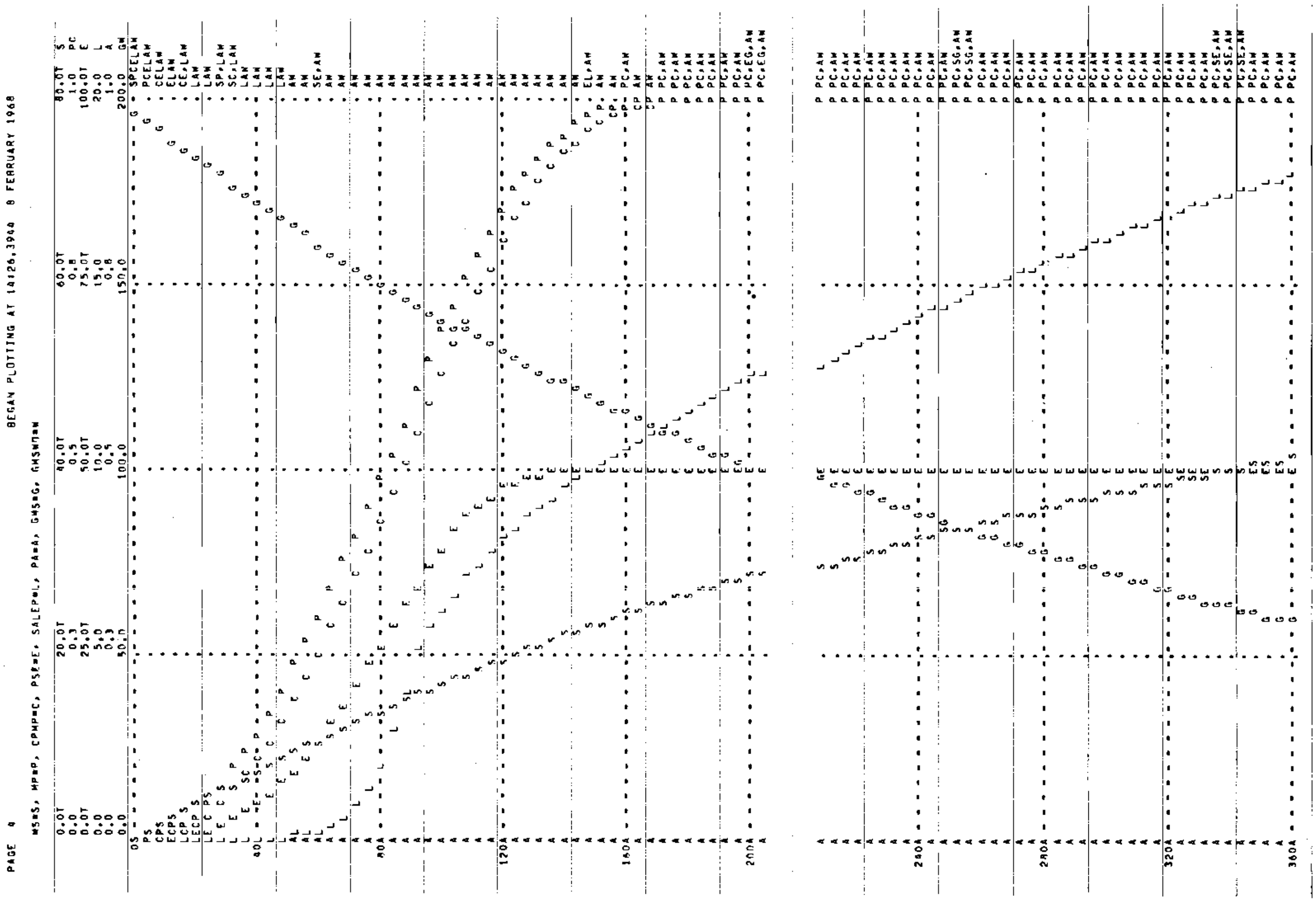

Figure 56. Section #4 - Run #1.

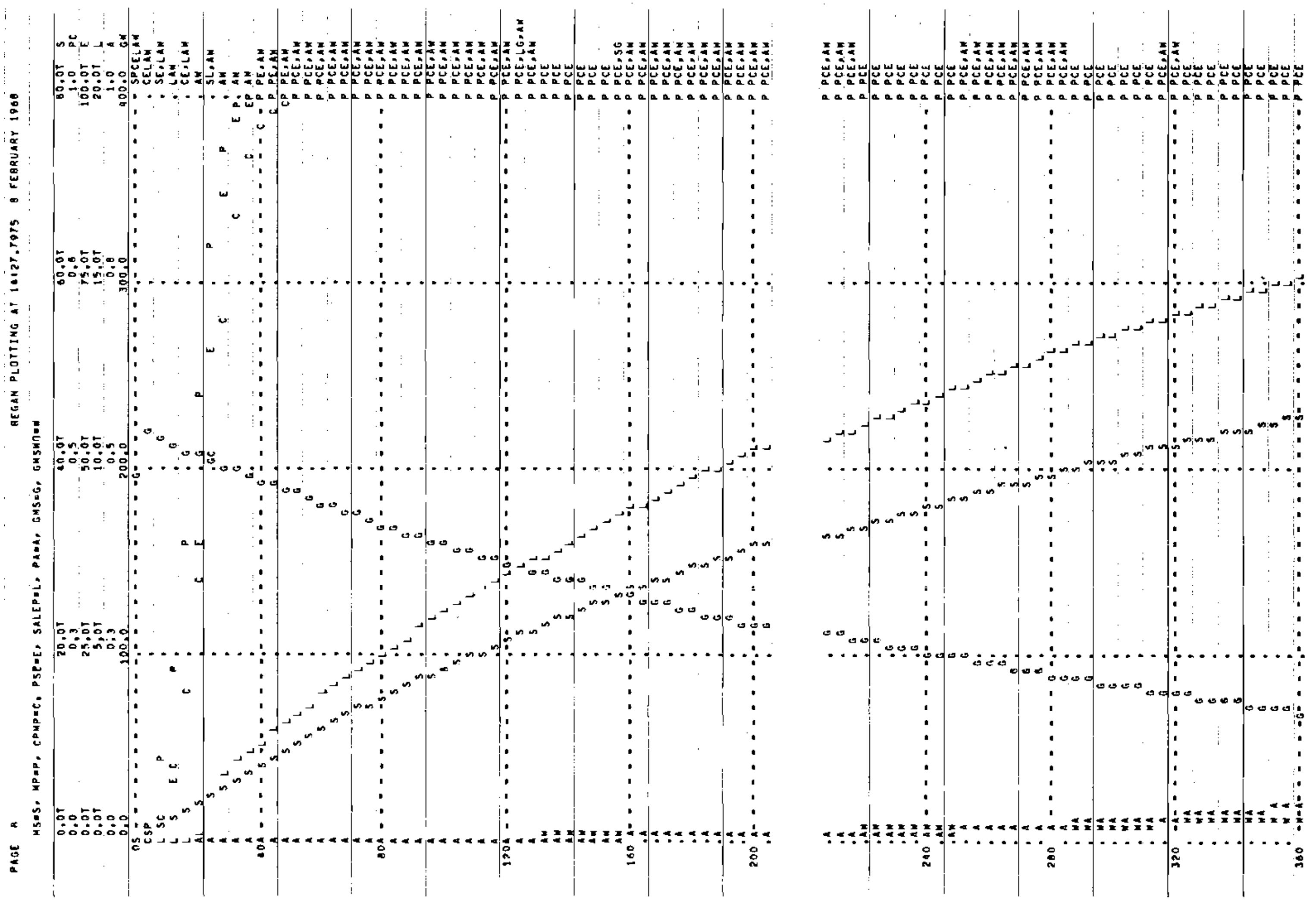

Figure 57. Section #4 - Run #2.

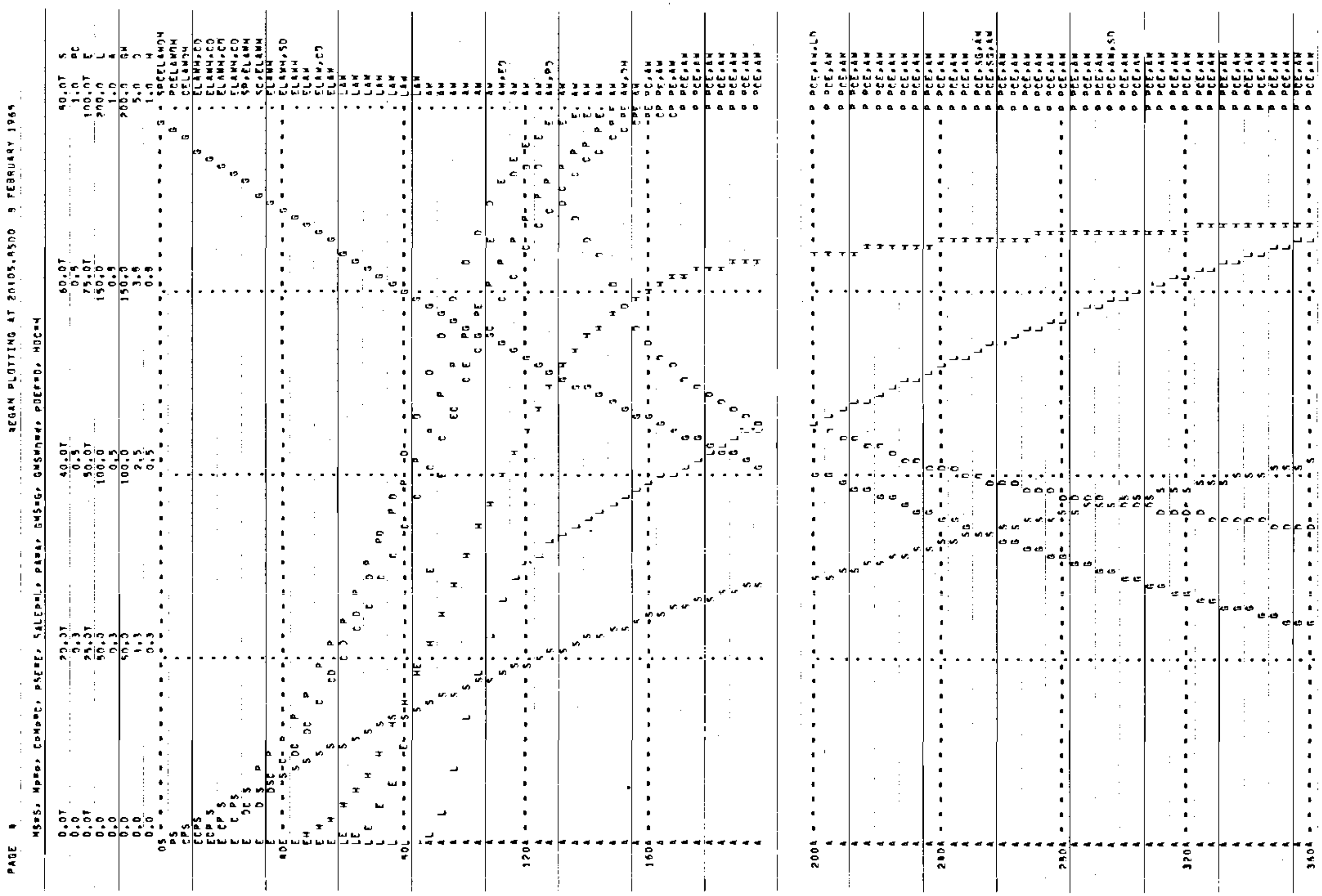

Figure 58. Section #5 - Run #1.

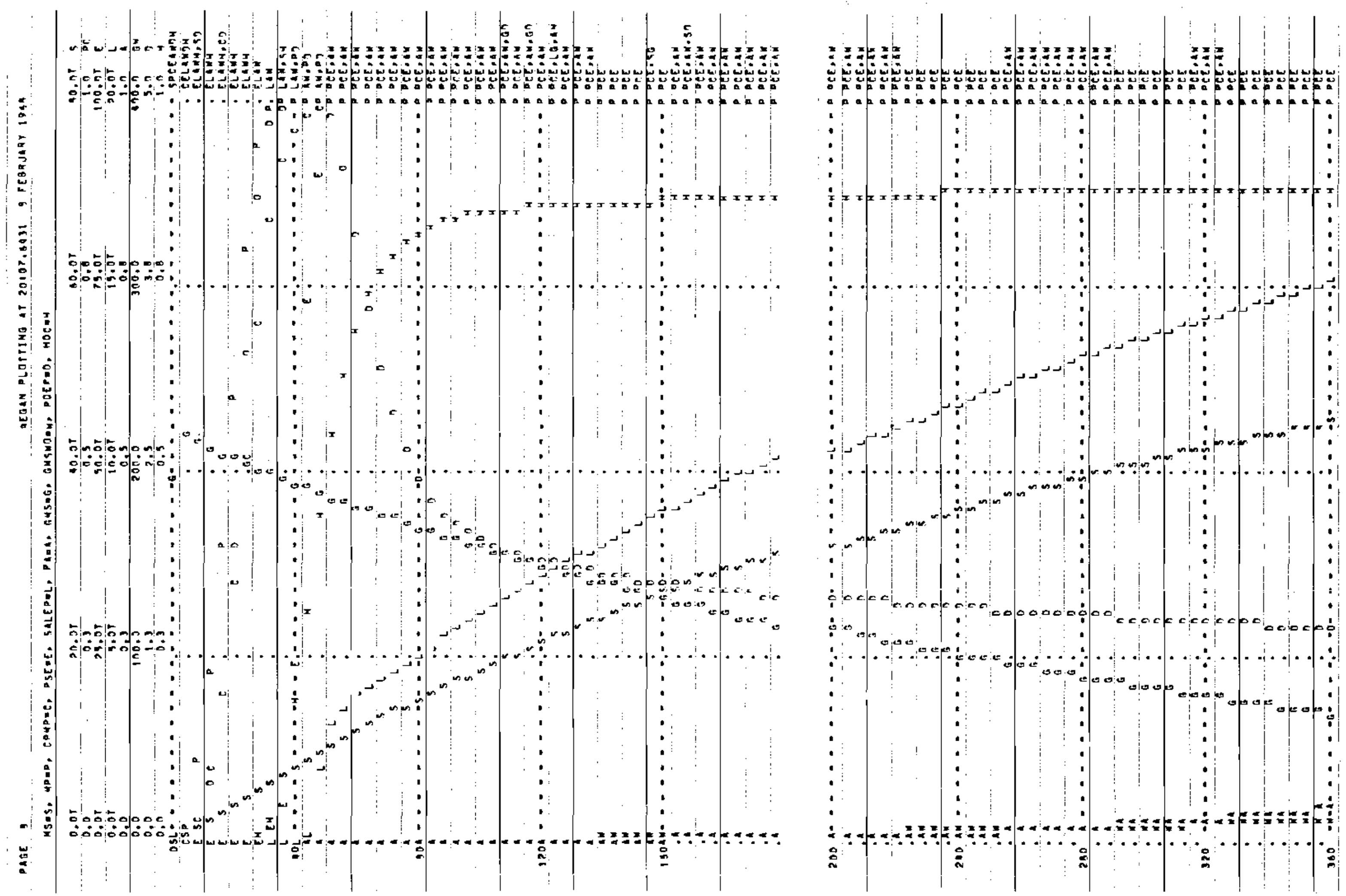

Figure 59. Section #5 - Run #2.

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BIBLIOGRAPHY

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